Research on Engineering Structures & Materials

journal homepage: http://www.jresm.org

MIM Research Group

Research Article

Sustainable approaches in the built environment with industrial waste and recycled products derived from construction and demolition waste

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Article Info

Article history:

Received 07 Feb 2023
Accepted 16 May 2023

Keywords:

Recycled concrete aggregates; Hollow cavity blocks; Compressive strength; Drying shrinkage; Structural cost efficiency

Abstract

The cost of construction becoming costlier day by day, because of the non-availability of sufficient natural materials. The exploration of natural materials leads to the depletion of natural resources. The increasing fuel prices and other miscellaneous costs make the production of conventional concrete costlier year by year. To address this issue, products derived from recycling construction and demolition waste and industrial waste having similar properties to that of natural aggregates and cement need to be identified, wherein, we can replace these in appropriate proportion to get the desired recycled concrete complement with conventional concrete. To explore this possibility, the study has been carried out by preparing the blocks with circular and rectangular cavities, using recycled concrete aggregate and coal ash. As we are using industrial waste materials this study ascertains the sustainability dimensions like, environmental and economic. An experimental procedure for finding compressive strength, water absorption, density, and drying shrinkage has been carried out. The percentage cost difference between conventional concrete and the recycled concrete block was determined using an economic analysis based on a remote matrix and raw material price. The most suitable proportion is found to be recycled concrete aggregates replacing 70% of natural aggregates and coal ash replacing 35% of cement, satisfying the mechanical properties of blocks but falling short of the durability characteristics. Based on the results, the structural-cost efficiency of distinct cavity blocks has been calculated. The concrete mix design and ideal mix are deduced solely for applications in Indian construction.

1. Introduction

Construction and demolition waste (CDW) accounts for 25–30% of all solid trash generated globally and is thought to produce more than 3 billion tonnes annually. Recycling CDW has been proposed to be necessary for the building industry to be sustainable in a circular economy given this grave environmental issue [1]. "According to a report by the Technology Information Forecasting and Assessment Council (TIFAC), new construction waste in India averages 50 kg per square meter, while the demolition of old buildings produces 300-500 kg per square meter of demolished waste". If it is presumed that 5% of existing structures are demolished each year, this trash will total 288 million tonnes. Construction and demolition debris comprises two types of waste: recycled concrete aggregate and recycled aggregate made from crushed conventional concrete. According to the Ministry of Urban Development (MoUD) report in India, recycled aggregate can bridge the gap between aggregate demand and supply, with the housing sector reporting a 55,000 million cubic meter aggregate shortage. Recycling construction and demolition waste (CDW) as an alternative concrete aggregate for concrete is one

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DOI: http://dx.doi.org/10.17515/resm2023.685ma0207

solution to all of these issues. There is a necessity for the creation of "Recycled aggregate concrete" (RAC) where aggregate reprocessing in the years ahead will be required due to a lack of natural resources. The output of fly ash and bottom ash from coal-fired electric power plants emits tonnes of combustion refuse each year. The majority of which is lightweight fly ash and heavier bottom ash that accumulates on the boiler floor, and the bulk of this ash is fated for landfills. Recycling and reusing C&D waste have numerous cost-cutting benefits. The cost of waste disposal land can be reduced, as can the labour costs associated with cleaning landfills. The modern building relies heavily on cement concrete hollow blocks. They are more affordable and superior than burned clay bricks because they are more durable, fire resistant, partially sound resistant, have good thermal insulation, and have a low dead load. Construction can be finished more quickly since concrete hollow blocks are often larger than conventional clay building bricks, require less mortar and are used for both framed, bearing walls, partitions, and panel walls. Recycled aggregate concrete blocks are synthesized, substituting recycled coarse aggregate for natural gravel or pebble and river sand for recycled fine aggregates. The strength of recycled concrete was equivalent to that of conventional concrete, as the ecological and financial benefits are quite good [2]. The material strength of RAC-based concrete is weaker than quartzite aggregate, but they are equivalent to granite aggregate-the second most often used aggregate. As a result, CDW may be utilized to make concrete with a characteristic strength of up to 30 N/mm^2 when natural aggregate is replaced with 100% recycled coarse aggregate [3]. The recycled aggregate concrete may be used in place of natural coarse aggregates in M20 grade concrete without compromising workability or strength [4]. Hammed (2015) [5] claimed a financial savings of 63.13 percent for recycled aggregate concrete generated by reusing concrete trash to build fresh concrete at the same demolition place. However, the cost savings are 12.62 percent when RAC is produced using recycled concrete aggregate bought from a recycling facility [6]. Increasing the amount of attached old cement mortar with the recycled fine aggregate replacement ratio results in a loss in compressive strength. While using recycled fine aggregate, the greatest compressive strength drop was 6.7%, 11.1%, 31.3%, and 50% for concrete with replacement ratios of 10%, 30%, 50%, and 100%, respectively [7]. It is evident that the compressive strength, regardless of the cement quantity or binder composition, is highly prone to the large subsistence of recycled fine aggregate (RFA) 100% [8,9]. In RAC, two significant elements to examine cost and energy usage. RAC can sometimes be more expensive or use more energy than virgin aggregate and is mostly controlled by travel distances [10]. The highest compressive strength achieved by recycled aggregate concrete cubes treated with epoxy resin with 25% replacement is 38.8MPa. Epoxy resin coating to recycled coarse aggregates reduces water absorption and improves the workability of concrete mix [11]. A sensitivity analysis-based case study in Thailand illustrates the viability of using recycled aggregates from Bangkok's economic aspects. It has been determined that the payback period for investments in recycled aggregate facilities is nine years [12]. The impact of using recycled concrete aggregates (RCA) in addition to superplasticizers on the mechanical, rheological, and overall shrinkage properties of concrete made with natural coarse aggregate and RCA has been studied. To demonstrate the change in mechanical properties and total shrinkage as an attribute of the concrete contents, inferences, and numerical relations are proposed. Concrete's compressive and flexural strengths at 28 days increased when RCA aggregate content is 60%. While the negative effects of using too much superplasticizer can reduce compressive strength by about 21% for materials with low w/c ratios. Concrete with RCA aggregates experiences overall shrinkage that is greater than regular concrete and proportional to the rate of substitution [13]. An experimental program was carried out to investigate the properties of RCA in comparison to natural aggregate. According to close observation, high-quality and acceptable structural concrete can be formed using RAC, which in turn is preliminarily dependent on the characteristics of demolished concrete [14]. Regarding the above-mentioned mechanical property coming to the durability aspect drying shrinkage is another key feature in the overall design of RCA. The drying shrinkage of RAC is measured over a 70-day test period with a 100% ratio and achieved a 95% rise in drying shrinkage [15]. Following that, researchers used RCAs to partially replace natural coarse aggregates (NCAs) in the preparation of normal- and high-strength RAC with w/c ratios of 0.26-0.75 and reviewed shrinkage actions. The results showed that as the RCA ratios increased, the drying shrinkage of RAC of varying strengths (w/c ratios) increased. These increases, however, ranged, ranging from 0.1% to 121.3% [16]. Good reliable construction is possible to make using RCA. Various mechanical test conducted on concrete where NCA: RCA ratio is 40:60 is found to be the logical and cost-effective and efficient way to use technology in the future [17]. Tyre waste has recently been used in a variety of ways for soil fortification. Waste tyre textile fiber is a byproduct of waste tyre processing. These unique wastes are regularly buried or burned in defiance of international law. This work uses an experimental design to demonstrate that these materials might be recycled and combined with soil to enhance the mechanical qualities of the mixture. According to the test results, adding fiber to the soil increases both its tensile and shear strengths. So, these wastes could be used to improve the mechanical qualities of many types of soils in geotechnical applications rather than being buried or burned [18]. Four different poorly graded sands with various particle size distributions underwent direct shear tests to ascertain their shear behaviors. 4 distinct poorly graded sands, each with a different median diameter have been chosen. Sand with larger particle sizes records a higher friction angle than soils with microscopic particles, according to the results. Also, it emerged from the experiments that sand with larger particle sizes had a higher dilation angle [19]. The present trend emphasizes sustainability in terms of substituting conventional materials with industrial byproducts as an environmentally friendly resource that may aid in the implementation of cost-savings and the use of green products. The concepts of structural efficiency (SE) and cost efficiency (CE) were established and assessed to demonstrate the relationship between compressive strength, toughened density, and cost per hollow block [20]. Portland cement is the principal source of carbon emissions from commercially produced concrete mixtures, accounting for 74% to 81% of total emissions [21]. Cement can be partially replaced by supplementary cementitious materials (SCMs) such as ground granulated blast furnace slag and fly ash and natural aggregates (NA) can be replaced with recycled aggregates (RA) [22]. Furthermore, sustainable recycled aggregate concrete (RAC) helps to limit the depletion of natural mineral resources [23]. SCM incorporation in NAC can lower carbon emissions and concrete costs, whereas partially substituting NA with RA results in equivalent emissions but a slightly higher cost for an equal design strength [24]. Based on the SVAGRIHA assessment, a conventional existing building star rating has been assigned in the case study inquiry on a 3BHK house in Bengaluru, Karnataka, India. According to the investigation, the current building construction practices do not meet the star green rating, so adopting renewable resources and materials with reduced embodied energy would be beneficial. Reducing waste, industrial recycling, efficiently utilizing energy, implementing green technologies, and protecting ecological resources are all examples of sustainable practices [25]. In practice, concrete hollow blocks are built of cement, cementitious ingredients such as fly ash, asbestos and conventional aggregates (M sand of 4.75mm and natural coarse aggregate of size 10mm). In India, a massive chunk of coal ash and construction demolition debris is generated, which is headed for landfills rather than being used as a raw material in concrete. To address this issue, recycling CDW waste to obtain recycled concrete aggregates should be undertaken. Previous research has shown the application of recycled concrete aggregates in combination with coal bottom ash on cubes. Utilizing untreated industrial waste (coal ash) and recycled CDW (RCA) to make circular and rectangular cavity block tests and ascertain the two dimensions of sustainability- enviro and economic centric applied to Indian construction add to new knowledge in this area of research, being a novelty. When coal ash is combined with water, it exhibits pozzolanic properties that allow it to generate cementitious compounds. Building Materials & Technology Promotion Council Ministry of Housing & Urban Affairs in India has policies to encourage the use of recycled concrete aggregates in building works as a sustainable construction approach. The recovered fine and coarse aggregates have been successfully used and verified for their suitability for use in concrete, with validation performed at the National Council for Cement & Building Materials - NCB Bhawan and other locations. Overall, the addition of recycled aggregates to natural aggregates offers several benefits, including resource efficiency, environmental stewardship, energy and cost savings, waste reduction, performance and adaptability, and regulatory issues.

The present study focuses on preparing recycled concrete hollow blocks of two different cavity shapes: rectangular cavity concrete block (RCB) and circular cavity concrete block (CCB). To create hollow block masonry units, this study aims to replace natural coarse aggregate (NCA) with recycled coarse aggregate (RC_CA), manufactured sand (M sand) with recycled fine aggregate (RC_FA), and cement with coal ash in varying ratios. The key parameter of the study is to find out and compare the compressive strength (fck), water absorption, density, drying shrinkage test, and cost efficiency study of hardened concrete RCB and CCB samples made of conventional concrete and recycled concrete (coal ash and RCA).

2. Methodology and Experimentation

The two distinct forms of cavity concrete blocks (RCB and CCB) are cast in after performing the basic property test on materials and mix design in accordance with IS 10262 (2019) utilizing conventional, waste and recycled materials. The key test on the concrete hollow block is done following IS 2185 (part 1):2005 specification. Considering the concrete cavity block manufacturing unit to be located at a place, the manufacturing cost of six distinct cavity blocks was investigated in terms of mix proportion dosage and material pricing including shipping expenses. Structural cost efficiency is one of the crucial factors to take into account for sustainability. Based on the strength and density delivered to the cost of producing a concrete cavity block, the structural cost-effectiveness of the specimens is assessed. The cost imposed by various concrete constituents has been compared, and different cavity block grades as per Indian construction scenarios have been illustrated. The sequence of study is shown in Fig. 1.

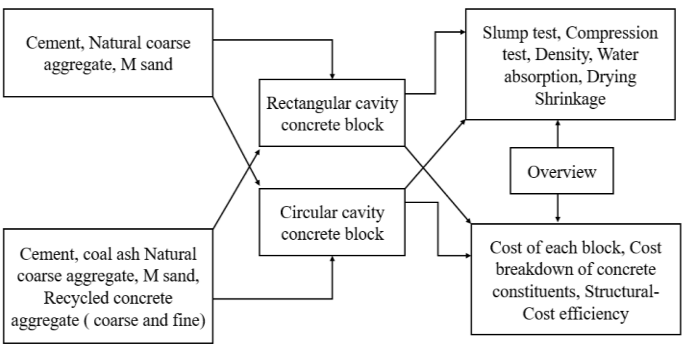

Fig. 1 Methodology for the study

2.1. Materials

M sand, natural coarse aggregate, recycled coarse aggregate (<10mm size), recycled fine aggregate (<4.75mm), OPC cement 53 grade, coal ash, and BASF master glenium superplasticizer are the components of the concrete block specimen utilized in this study. These materials are used to create cavity concrete blocks in accordance with IS 10262 (2019). RCA is bought from a CD waste recycling plant located near Yelahanka, Bengaluru. Coal ash is collected from the bottom of a furnace in a clay brick manufacturing operation where coal was used as a fuel source and sieved to eliminate undesirable components. Fig. 2 depicts the various materials utilized in the study of mixed-proportion concrete samples that were not subjected to any processing at the casting site. The material's physical appearance is shown below, providing a visual acceptance of the difference between recycled or waste materials and natural materials.

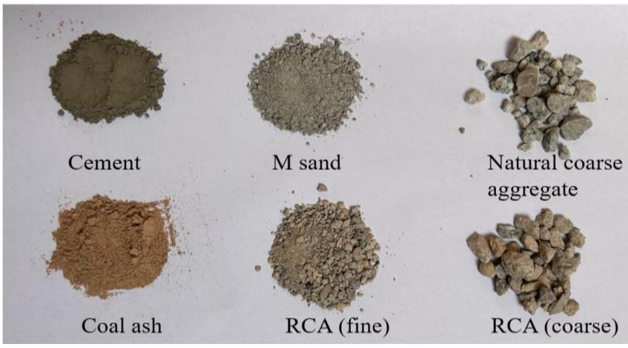

Fig. 2 Concrete materials used in the study

2.2. Mix Design and Mix Proportion

As there is no special mix design for recycled aggregate concrete, the study followed the specifications for conventional concrete (IS 10262-2019). Six concrete mix proportions are considered and 12 concrete hollow blocks type of each 6 rectangular and circular cavity blocks have been cast. The water cement ratio is adjusted based on the RCA water absorption with the addition of recycled concrete aggregate. The mix ratios obtained in this experimental study are. Mix calculation outcomes per unit volume of concrete are displayed in Table 1 along with the mix ratio, which was determined to be 1:1.39:2.91 (cement: fine aggregate: coarse aggregate) for both cavity blocks.

Table 1. Mix proportion of concrete mix design

Mix type	Cement kg/m³	Coal bottom ash kg/m³	NCA kg/m³	RC_CA kg/m³	M sand kg/m³	RC_FA kg/m³
Mix 1 and 2	483.63	-	1407.36	-	672.24	-
Mix 3 and 4	314.35	169.27	422.46	984.9	201.43	470.56
Mix 5 and 6	265.99	217.63	141.06	1266.3	67.22	605.01

The proportions of RCA in the concrete cavity block mixture are considered as per the IS:383(2016). Table 2 below displays the additional superplasticizer dosage and the water-cement ratio (W/C). Since recycled aggregates often have higher water absorption capabilities, the saturated surface dry conditions of the aggregate were maintained prior to the start of the mixing processes. In order to improve the performance of concrete in terms of workability and compressive strength, the dosage of superplasticizer in RAC is doubled.

Table 2. Different concrete mix percentages for different cavity block specimens

Mixes	Mix Type	HBS	Concrete Mix Ratio	(w/c)	SP %
Mix-1	Conventional concrete	R1, C1	100% (cement)+100% (NCA)+100% (M sand)+SP	0.40	0.5%
Mix-2		R2, C2	100% (cement) + 100% (NCA) + 100% (M sand)	0.45	-
Mix-3	Recycled concrete	R3, C3	35% (coal ash)+65% (cement)+70% RCA (Coarse)+30% (NCA)+70% RCA (Fine)+ 30% M sand+SP	0.40	1%
Mix-4		R4, C4	35% (coal ash) + 65% (cement)+70% RCA (Coarse)+30% (NCA)+ 70% RCA (Fine)+ 30% M sand	0.45	-
Mix-5		R5, C5	45% (coal ash)+55% (cement)+90% RCA (Coarse)++ 10% (NCA)+90% RCA (Fine)+10% (M sand) +SP	0.40	1%
Mix-6		R6, C6	45% (coal ash) + 55% (cement) + 90% RCA (Coarse)++ 10% (NCA) + 90% RCA (Fine)+10% (M sand)	0.45	-

2.3. Preparation of Specimen

Rectangular cavity block (RCB) and circular cavity block (CCB) of size 500*100*100mm maintaining a consistent bed thickness of 25mm are prepared. RCB is provided with a face shell thickness of 25mm and a web thickness of 50mm. In the instance of the CCB block, the face shell thickness is 50mm and the web thickness is 60mm. Compressive strength, water absorption, and block density are calculated as per the IS2185(part 1) 2005 code. Fig. 3 depicts the casting technique used for the study's specimens.

Fig. 3 Casting of RCB and CCB testing specimens for the study

2.4 Basic Property Test of Concrete Materials

The fundamental specifications for concrete constituents used in the mix design for the objective strength M30 are shown in Table 3. The recycled fine aggregate fineness modulus is significantly greater than that of M sand, indicating that RFA is coarser than M sand. As the age of the recycled aggregate increases the specific gravity of the aggregate decreases. The source of the aggregate and the old mortars clinging to it are the key elements impacting the recycled concrete aggregate's capacity to absorb water. The standard consistency of coal ash was experimented to be more than cement but was in the limited range as prescribed by IS5513-(1976) and IS4031-1998.

Table 3. Basic material property test result

Concrete Materials	Specific Gravity	Water Absorption (%)	Fineness Modulus
M Sand	2.61	8.1	4.83
RCA (Fine)	2.44	4.74	5.525
Natural Coarse (NCA)	2.54	<1	2.066
RCA (Coarse)	2.24	6.38	1.961
OPC 53 Grade Cement	2.97	NA	NA
Coal Ash	2.41	NA	NA

2.5. Sieve Analysis of Aggregates

The aggregate's particle size distribution and grading curves are shown in Fig. 4 and Table 4. Despite that both natural and recycled aggregates showed a similar nature, they could not have hindered the workability of fresh concrete. RCA gradation depends on the source of demolished concrete and the recycling method. RCA utilized in the study tends to have a high percentage of finer particles than the conventional aggregate. RCA (fine) falls under Zone 1 and M sand falls in Zone 2 as per the gradation under clause 6.3 in IS 383 (2016). The higher percentage fraction variation is observed in the 300-75-micron sieve in RC_FA and 4.75mm micron sieve in RC_CA.

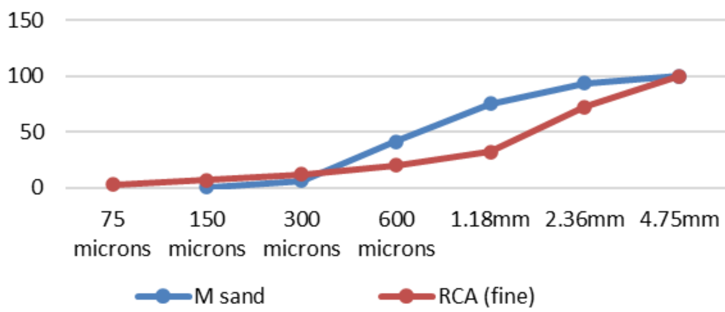

Fig. 4 Grading curve of fine aggregate

Table 4. Particle size distribution of RCA and NCA

IS Sieve	% passing NCA	% passing RCA (coarse)
20mm	100	100
12.5mm	100	99.7
10mm	91.8	83.1
4.75mm	1.6	21.1

2.6 Slump, Compressive Strength, Density, Water Absorption

Concrete workability relates to the uniformity of concrete in the fresh state and is partly related to its yield stress. The workability of the concrete is inferred based on the slump value of the concrete mixture as prescribed in code IS 1199 (2018). Compressive strength test is done in the universal testing machine where plates are kept at the bottom and top of the specimen to prevent failure at the hollow section and to distribute the load equally along the surface area. The procedure specified in IS 2185 (2005) has been followed in terms of block density and water absorption (annexures C and E) calculation.

2.7. Drying Shrinkage Test

The drying shrinkage test is carried out using a length comparator as the tool and is observed in Fig. 5. Six different concrete mix samples are cast in a 7.5x7.5x30 cm mould and left for curing for about 28 days. As the specimens are taken out of the water, each specimen's length must be measured (wet measurement, L1). The samples are then kept in an oven set at 50°C for 44 hours. Samples are described as having a dry length, L2, after being dried in an oven. The formula below is used to calculate the sample's drying shrinkage.

Drying shrinkage (%) = (L1-L2)/L2 X 100

Fig. 5 Drying shrinkage test using length comparator

2.8. Cost Analysis

Taking into account the concrete hollow block manufacturing facility in Hebbal, Bengaluru. The cost of manufacturing hollow blocks of the various concrete composites considered in the study is calculated by employing recycling and industrial unit vendor selling prices. The cost estimation for the hollow block with superplasticizer added is assumed to be the same as hollow blocks created without superplasticizer. Consequently, the value of the increased master glenium price per block is negligible. Fig. 6 depicts the availability of raw materials concerning the hollow block factory's distance matrix. Recycled aggregates are found to have a net purchasing cost that is half that of natural aggregates. The cost of coal ash is imposed more on transportation than on its retail price.

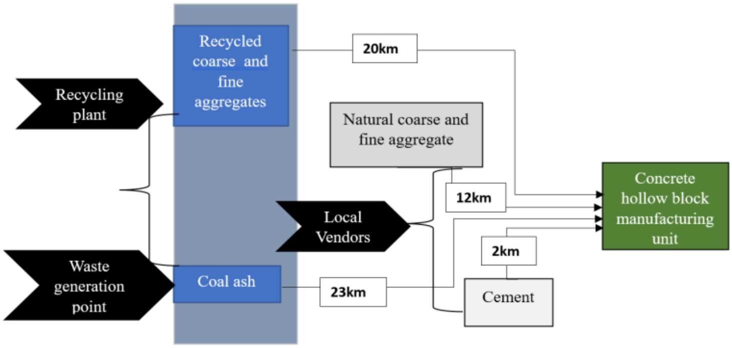

Fig. 6 Distance matrix of cavity block manufacturing unit

2.9. Structural -Cost Efficiency of The Different Cavity and Concrete Composite Block

To compare the conventional and industrial by-product-based hollow blocks, the idea of structural-cost efficiency (SCE) was established and assessed to specimens into a comparable platform. Structural-cost efficiency is calculated by the equation 1 as mentioned below.

$$SCE = \left(\frac{fck}{D}\right) + \left(\frac{fck}{C}\right) \tag{1}$$

fck =compressive strength of block unit (MPa)
D= Density of the unit block (Kg/m^3)
C= Cost per unit block (INR)

3. Results

In this section the results obtained from the study, related to fresh and hardened concrete using various mix proportions have been outlined.

3.1. Fresh Concrete Test

Different slump pattern of various concrete mixtures is observed in Fig. 7. The slump value of the concrete mixture is subsiding as the percentage of RCA increases and the value ranges from 30-65mm which is within the range per code IS 1199 (2018) and is shown in Fig. 8.

Fig. 7 Slump pattern of different concrete mix

In the CDW crushing procedure, the quantity of adhered mortar causes poor workability and large slump loss in recycled aggregate concrete. According to experiment observation, using a superplasticizer is advised to make RAC more workable.

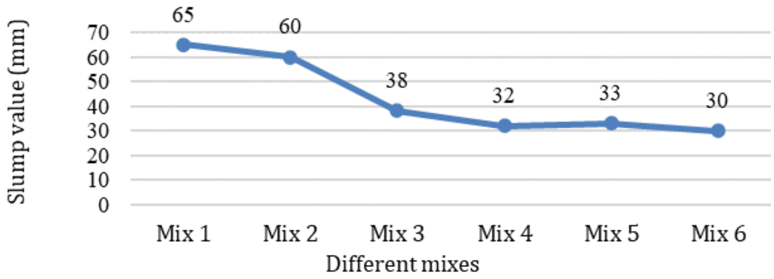

Fig. 8 Slump value of different concrete mix

3.2. Hardened Property Test Results

The compression test of these 12 cavity blocks (RCB and CCB) after 28 days of curing has been performed, and variation in strength test results of a different concrete mixture is shown in Fig. 9. Given the failure status of recycled concrete masonry block, it is clear that the top face and the weak points in joints where penetration cracks had first appeared before the entire specimen was ultimately destroyed. This was primarily caused by grooves on the top surface, making forming a failure surface simple. The lowest and maximum compressive strengths of various RCB and CCB concrete compositions are shown in Table 5. The statistical data are analyzed using R Studio to determine the standard deviation and coefficient of variation for each of the 12 different blocks which are shown in Table 5 below.

Table 5. Summary of test results of compressive strength (fck)

Block type	Minimum fck	Maximum fck	Standard deviation	Coefficient of variation
R1	12.98	13.27	0.1181	0.8981
R2	10.5	11.31	0.3245	2.9723
R3	12.29	12.33	0.2963	2.4508
R4	6.9	7.53	0.2246	3.1195
R5	9.77	10.28	0.1874	1.8785
R6	5.6	6.09	0.2591	4.399
C1	26.78	28.82	0.7404	2.6510
C2	25.1	26.1	0.4123	1.6105
C3	14.99	15.54	0.2198	1.4399
C4	10.65	10.98	0.1238	1.1417
C5	11.25	11.98	0.3035	2.6169
C6	7.12	7.71	0.2250	3.004

The highest strength is achieved by CCB (C1 and C2) and the fck value is ranging from 21.91 MPa without a superplasticizer and 24.92 MPa with a superplasticizer. There is a difference in the characteristic strength between recycled concrete block and conventional concrete block, varying from 41% to 61% less for CCB and 10% to 25% less for RCB. Since coal ash is rehydrating material and contains calcium oxide and recycled aggregates diminishes the aggregate–mortar interfacial transition zone of recycled aggregate concrete, thus declining its mechanical strength. In the wake of the block's large hollow area and thinner web, RCB's compressive strength is 40%-12% weaker than CCB's for the same concrete mix proportion. The inclusion of a superplasticizer in mixes 3 and 5 increased block strength by up to 40%, owing to the production of a homogeneous mixture with a low water-cement ratio to offset excessive water absorption in recycled aggregate concrete.

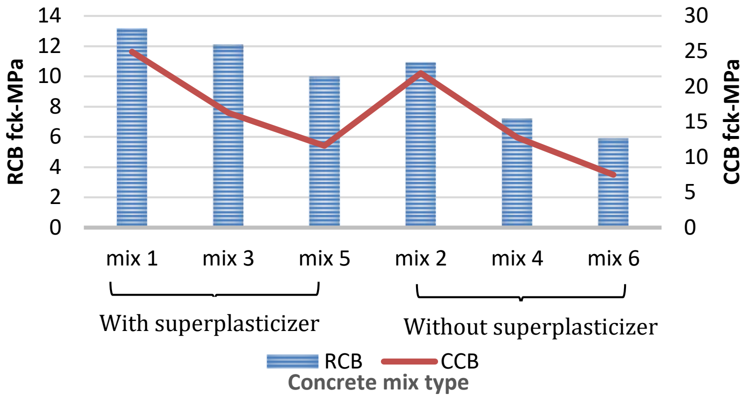

Fig. 9 28 days compressive strength (fck) of different cavity block

3.3. Grading of Conventional Concrete and Recycled Concrete Block

The block density of recycled concrete block is 0.1 times lower than a conventional concrete cavity block. This is due to the porosity and low specific gravity. Water absorption of both RCB and CCB- conventional concrete and recycled aggregate concrete are below 10% which is acceptable in practice. The density of the considered blocks in the study is ranging from 1362- 1940 kg/m3 wherein RCB is less dense compared to CCB due to the increased content of concrete mixtures.

Table 6. Comparison of conventional and recycled concrete block

Specimens	Mix type	Density (kg/m^3)	Water absorption	Block grade
RCB	Mix 5	1362	6.68%	B
	Mix 6		5.59%	
CCB	Mix 5	1752	7.8%	A
	Mix 6		7.49%	
RCB	Mix 3	1565	6.32%	A
	Mix 4		5.99%	
CCB	Mix 3	1835	6.78%	A
	Mix 4		6.56%	
RCB	Mix 1	1633	4.3%	A
	Mix 2		4.4%	
	Mix 1	1940	5.67%	A
CCB	Mix 2		5.9%	

There is a slight decrease in water absorption of the concrete block when a superplasticizer is used due to its adsorption capacity. Water absorbability of concrete increases with the addition of recycled concrete aggregates and the replacement of coal ash. This may be because of the high-water absorption capacity of the adhered mortar in the recycled concrete. Table 6 presents the grade of each block type made of different concrete mixes based on the obtained water absorption, density, and compressive strength results.

3.4. Drying Shrinkage Test

The shrinkage of the concrete samples regarded for the study after 28 days is depicted in Table 7. Each mix was tested using an average of four samples and the drying shrinkage percentage ranged from 0.009 to 0.084. According to the experimental findings, the increased moisture content and reduced strength of RCA have resulted in increased drying shrinkage of recycled concrete mix.

Table 7. Drying shrinkage of different concrete mixtures

Concrete Mix Type	Drying shrinkage (%)
Mix 1	0.031
Mix 2	0.002
Mix 3	0.075
Mix 4	0.069
Mix 5	0.091
Mix 6	0.084

As per the Indian standard code, the maximum allowable percentage is 0.006%. Recycled concrete mixtures is exhibiting shrinkage of up to 0.09% and the rate of shrinkage in samples with superplasticizer is more. This is primarily because the paste volume increased. Superplasticizers lower the surface tension of the water in the concrete mix, enabling the addition of more water. Due to the increased surface area of the paste particles, moisture in the concrete evaporates, increasing the amount of shrinkage.

3.5. Cost Ratio of RCB and CCB Block Composites

Taking into account the mass of composite materials for RCB and CCB, Fig. 10 and Fig. 11 shows the cost of each material contributing to each cavity block in Indian Rupees (INR-₹). From the surveillance of the below figures, it can be noted that cement is the major expensive component used to make concrete, followed by coarse aggregate and then fine aggregate. RCA incurs more transportation costs than it does net market value.

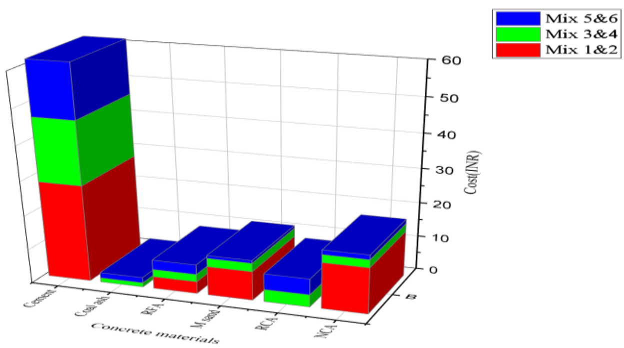

Fig. 10 CCB composites cost ratio (INR)

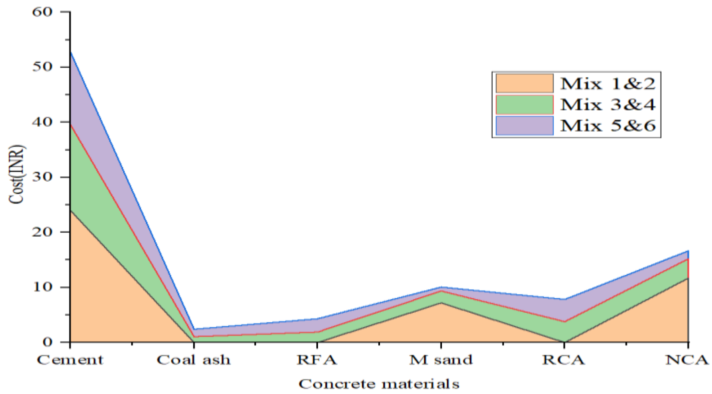

Fig. 11 RCB composites cost ratio (INR)

3.6. Structural-Cost Efficiency of The Different Cavity and Concrete Composite Blocks

The Pricing of two distinct concrete blocks with varying cavities is shown in Fig. 12, along with structural-cost efficiency (SCE) values. Mix (1,2) costs 42.9₹ for one RCB block while one CCB block is 47.82₹. Mix (3,4) RCB costs 32.7₹ and CCB costs 37.4₹. Mix (5,6) costs 29.6₹/CCB and 27.92₹/ RCB. Mix (3,4) and Mix (5,6) cavity blocks have been observed as 23% and 31% less expensive compared to conventional concrete mix (1,2) including transportation costs.

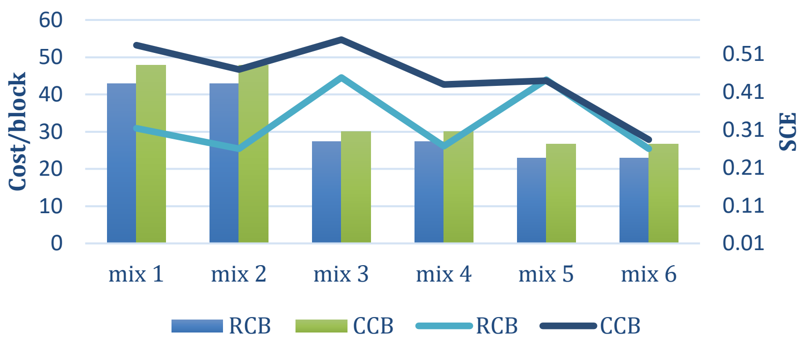

Fig. 12 Structural-Cost efficiency of block

Since RCB blocks have more cavity space and a lower material consumption rate than CCB blocks, they are relatively less expensive. When RCA (fine and coarse) and coal ash are used, mix 3 blocks (RCB, CCB; R3, C3) is found to have the highest structural- cost-effectiveness. SCE increased by about 30% and 3% in the R3 and C3 blocks, respectively, for the conventional block. Meanwhile, SCE in the R5 and C5 blocks was found to be equal.

The government, businesses and the general public must all work together in a concerted effort to promote the use of recycled materials in building construction. The government of India should emphasize increasing the quality of recycled materials and finding novel ways to use them in building construction. Education and awareness initiatives might be developed to spread the word about the advantages of employing recycled materials in building construction. It is advisable to encourage contractors and building firms to use recycled aggregate by offering incentives. This can aid in the development of a sustainable supply chain for these commodities.

Among the 17 sustainable development goals (SDG) the current research meets the 9th goal: Industry, Innovation, and Infrastructure; the 12th goal: Responsible Production and Consumption; 13th Goal: Climate Action. Using RCA and coal ash to accomplish the 9th Industry, Innovation, and Infrastructure target is one of the 17 Sustainable Development Goals. 12th: Responsible Production and Consumption. 13th Goal: Climate Action. Building sustainable infrastructure with enhanced resource efficiency supports economic development by focusing on cheap and fair public access. Recycling and reusing building and demolition debris could help to achieve sustainable management and efficient use of natural resources. It aids in the creation of jobs by requiring labour from the beginning to the end of the manufacture of recycled concrete aggregates from the source site. Using the approach of substituting possible industrial waste in raw form or recycled pattern would assist to cut carbon dioxide emissions from conventional material production.

Recycled concrete aggregates in concrete production can be used only in metropolitan cities, Since the rate of construction and destruction (C&D) activity is more in these places. Usage of these waste and recycled materials will not be applicable for districts and taluk places because of lower C&D activities and transportation of these waste from large generation areas to smaller towns will negatively impact on enviro and economic dimensions of sustainability.

4. Conclusion

While developing load-bearing wall units that adhere to IS 2183 criteria, supplementary cementitious materials (SCM) such as coal ash up to 45%, can partially substitute cement and natural aggregates can be replaced with recycled concrete aggregates up to 90%. The passive benefits of using recycled concrete aggregates prevent the depletion of natural mineral resources and maintaining sustainable CDW management practices. According to the economic analysis, considerable cost reduction is observed in substituting NCA with RCA. However, the substitution of coal ash for cement has shown a significant impact on cost reduction.

The following conclusions are drawn from the study

- The workability of recycled concrete is lower than conventional concrete mix, but the slump value is within the acceptable limit for concrete masonry as per code IS 1199 (2018). The reduction in slump value is due to contamination of RCA the adhered mortar.
- Recycled coarse and fine aggregates can be used in making hollow block masonry units with a minimum of 5MPa characteristic strength. This can be employed as a load-bearing walling element by replacing natural aggregates of up to 90% by RCA with the addition of coal ash replacement of up to 45% as a supplementary cement material.
- The inclusion of a superplasticizer improved both the slump test and the compressive strength property. It reduced the water content of the mix, enhanced the cement particle spread, and increased compaction effectiveness, resulting in denser concrete. The workability of recycled concrete improved by 14%-16% when 1% SP was added to the cement weight. Superplasticizers can be applied to concrete hollow blocks to increase RAC compressive strength by 40%.
- Since the mass of RCA in unit CCB is greater than that of RCB, the water absorption and density of the CCB block are greater than that of RCB. The density of conventional hollow blocks is larger than recycled concrete hollow block due to

the pore structure of RCA and the low specific gravity of non-conventional materials.

- The RCA severely impacted the recycled concrete 28-day drying shrinkage by up to 0.8% - 0.9% for an RCA replacement ratio of 90%. The drying shrinkage characteristics of recycled concrete hollow blocks are not satisfied. Even though the addition of superplasticizers was supposed to increase workability and compressive strength, the durability property diminished. This is because recycled concrete undergoes bleeding where the water rises to the top of the concrete and volatiles having left voids, which leads to concrete shrinkage.
- Cement is indeed the largest share with the highest consumption cost in the creation of concrete components. Substituting recycled concrete aggregate and coal ash for traditional concrete materials makes it possible to manufacture hollow block walling units with a minimum characteristic strength of 5 MPa at a minimum cost savings of 30%.
- The best mix (mix 3) for both cavity blocks is 35% (coal ash) + 65% (cement)+70% RCA (Coarse)+30% (NCA)+ 70% RCA (Fine)+ 30% M sand+ Superplasticizer. This concrete mix hollow block is considered to be a grade A block with good compressive strength, and high structural-cost efficiency upon improving the drying shrinkage property.

Future scope of the study

- Improve on the durability property of concrete mix (drying shrinkage) where the concentration of recycled aggregate is 70% and coal ash is 35% and above.
- To experiment on different size hollow blocks considering the current project mix proportion.

Acknowledgment

I would like to acknowledge and give my warmest thanks to my research supervisor for his advice and support in carrying me through all the stages to write this research article. My sincere thanks to project students, teaching, and nonteaching staff for their help in carrying experimental project.

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