A Study Of Sustainable Solution Of Recycled Concrete Waste Materials

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Abstract

The idea of recycling concrete waste obtained from demolished buildings aims at preserving the environment. Indeed, the reuse of concrete as aggregate in fresh concrete help to reduce the expenses related to construction and demolition (C&D) waste management and, especially, to protect the environment by reducing the development rate of new quarries. This paper presents the results of an experimental study conducted on masonry blocks containing aggregates resulting from concrete recycling. The purpose of this study is to investigate the effect of recycled aggregates on compressive strength of concrete blocks. Tests were performed on series of concrete blocks: ten series each made of different proportions of recycled aggregates, and one series of reference blocks exclusively composed of natural aggregates. Tests showed that using recycled aggregates with addition of cement allows the production of concrete blocks with compressive strengths comparable to those obtained on concrete blocks made exclusively of natural aggregates.
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Keywords: *Recycled concrete waste materials, recycled coarse and fine aggregate properties*

1. Introduction

1.1 General

Use of recycled aggregate in solid blocks can be useful for environmental protection. The application of recycled aggregate has been in use in many construction projects of western–countries. Many countries are giving relaxation for infrastructure for increasing the use of recycled aggregate. Rate of growth of urbanization in India is very high due to industrialization. Growth rate of India is reaching 9% of Gross Domestic Product. [1] Rapid infrastructure development requires a large quantity of construction materials, land requirements & the site. For large construction, concrete is preferred as it has longer life, low maintenance cost & better performance. For achieving GDP rate, smaller structures are giving up for new tall structures.

Protection of environment is a basic factor which is directly connected with the survival of the human race. Parameters like environmental consciousness, protection of natural resources, sustainable development, play an important role in modern requirements of construction works. Due to modernization, demolished materials are used as land fill & not used for any purpose. Such situations affect the fertility of land. Out of the total construction demolition waste, 40% is of concrete, 30% ceramics, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. For production of concrete, 70-75% aggregates are required. Out of this 60-67% is of coarse aggregate & 33-40% is of fine aggregate. [1]

From environmental point of view, producing natural aggregates of 1 ton, 0.0046 million tons of carbon is emitted where as 1ton recycled aggregate produces only 0.0024 million ton carbon. Considering the global consumption of 10 billion tons/year of aggregate for concrete production, the carbon footprint can be determined for the natural aggregate as well as for the recycled aggregate. The use of recycled aggregate generally increases the drying shrinkage creep & porosity to water & decreases the compression strength of concrete compared to that of natural aggregate concrete. It is nearly 10-30% as per replacement of aggregate. Recycling reduces the cost by about 34-41% & CO_2 emission (LCCO2) by about 23-28% for dumping at public / private disposal facilities. [6]

1.2 Advantages of recycling of construction material's:-

- Used for construction of precast & cast in situ gutters & kerb's.
- Cost saving: - There are no detrimental effects on concrete & it is expected that the increase in the cost of cement could be offset by the lower cost of Recycled Concrete Aggregate (RCA).
- Save environment: - There is no excavation of natural resources & less transportation. Also less land is required.
- Save time: - There is no waiting for material availability.
- Less emission of carbon due to less crushing.

1.3 Limitations or disadvantages of recycling of construction material:-

- Less quality (e.g. compressive strength reduces by 10-30%).

- Duration of procurement of materials may affect life cycle of project.
- Land, special equipments machineries are required (more cost).
- Very high water absorption (up to 6%).
- It has higher drying shrinkage & creep.

1.4 Objectives of the study:-

- To find out the % use feasible for construction.
- To reduce the impact of waste materials on environment.
- To carry out different tests on recycled aggregates & natural aggregates & compare their results.
- To find out the ways of cost saving such as transportation, excavation etc.

1.5 Scope of the study:-

- Brand of cement used for study is confined to 53 grade Ordinary Portland Cement.
- Recycled coarse aggregate used for the study is obtained from a demolished 5-storied building from North Paravur .
- Recycled fine aggregate used for the study is obtained by sieving the crushed recycled coarse aggregate. (Materials passing through 4.75mm and retained on 150 microns).
- Solid blocks of different combinations using recycled coarse aggregate and recycled fine aggregate were cast and different test were conducted on these.

1.6 Methodology:-

Plain cement concrete (PCC) & reinforced cement concrete is collected from demolition sites. This collected material is crushed by hammer to separate the aggregates & reduce their sizes in smaller fraction. On these separated aggregates various testes are conducted in laboratory as per Indian Standard code & their results are compared with natural aggregates. Solid blocks with dimensions corresponding to Indian Standard codes are cast using these natural aggregates and recycled aggregate. Blocks with Recycled Coarse Aggregate and Recycled Fine Aggregate were prepared.Recycled aggregate reduces the impact of waste on environment. By using some percentage in construction sector, cost is saved, due to reduction of transportation & manufacturing process.

2. Materials and Their Properties

2.1 Materials

2.1.1 Cement

Grade 53 Ordinary Portland Cement conforming to IS 12269-1987[3] was used in this study. The brand of cement used was Dalmia superroof cement. The cement has been tested for various properties and the result obtained satisfy the IS specification. The physical properties of cement are shown in Table 1

Table 1: Properties Of Cement

SL No.	Properties	Value	IS Specification And Test procedure
1	Specific gravity	3.15	IS:4031
2	Standard consistency	35%	IS:4031 & IS269
3	Initial Setting time in minutes	128	>30,IS:4031 & IS269
4	Final Setting time in minutes	364	<600, IS:4031 & IS269

2.1.2 Natural Fine Aggregate

The fine aggregate used in this experimental investigation was manufactured sand (M-sand) confirming to zone II.

a) Specific gravity

The specific gravity of fine aggregate is found by using pycnometer and was done according to IS 2386(Part 3)-1963[4]. The specific gravity of natural fine aggregate was obtained as 2.68.

Average value of specific gravity for natural fine aggregate obtained is 2.68

b) Water absorption

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS 2386(Part 3)-1963[4]. The water absorption of natural fine aggregate was obtained as 13.89%.

c) Sieve analysis

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregate and according to it the grading of aggregates can be done. According to sieve analysis fineness modulus is found out and it is a ready index of coarseness or fineness of the material. The test was conducted according to IS 2386(Part 1)-1963[4]. The results obtained from sieve analysis are shown in Table .2 and the Particle size distribution graph for natural fine aggregate is shown in Fig .1.

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Table 2 : Sieve analysis of natural fine aggregate

Sieve(mm)	Weight retained(g)	% of weight retained	Cumulative %weight retained	% of finer
10	0	0	0	100
4.75	6	0.6	0.6	99.4
2.36	245	24.5	25.1	74.9
1.18	229	22.9	48	52
0.6	164	16.4	64.4	35.6
0.3	145	14.5	78.9	21.1
0.15	106	10.6	89.5	10.5
Pan	105	10.5	100	0

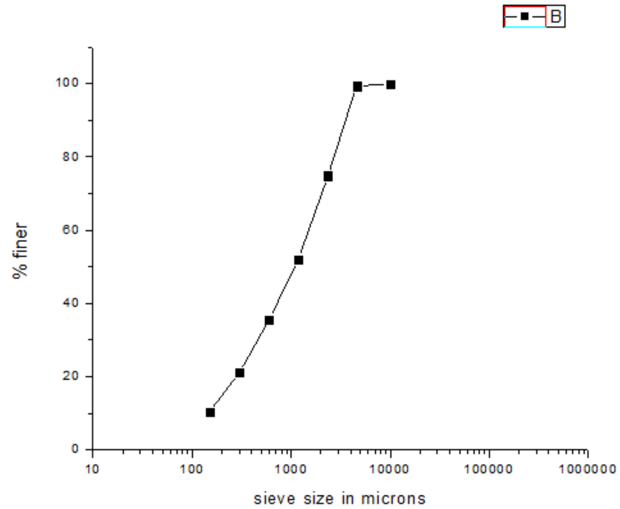

Fig .1 Particle size distribution graph for natural fine aggregate

2.1.3 Natural Coarse Aggregate

Crushed granite aggregate particles passing through 12mm and retained on 4.75mm I.S sieve was used as natural coarse aggregates. Coarse aggregate contributes significantly to the structural performance of concrete, especially strength, durability and volume stability. It occupies more than 70 % of the volume of concrete.

a) Specific gravity

The test was conducted as per IS: 2386 (part III)-1963[3], and the value of specific gravity of natural coarse aggregate is 2.688. According to M.S Shetty [5] in Concrete Technology, the average specific gravity of rock varies from 2.6-2.8.

Average value of specific gravity for natural coarse aggregate is 2.688

b) Water absorption

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. The water absorption of the natural coarse aggregates is found according to IS: 2386 (Part 3) – 1963 [4].

Water absorption of 12 mm aggregate = 1.95%

Water absorption of 6mm aggregate = 2.5%

c) Sieve analysis

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregates and according to it grading of aggregates can be done. The sieve analysis is done as per IS 383-1970 [4]. The particle size distribution is shown in Table.3 and the Particle size distribution for natural coarse aggregate is shown in Fig .2

Table 3 Sieve analysis of natural coarse aggregate

Sieve(mm)	**Weight retained(g)**	**% of weight retained**	**Cumulative %weight retained**	**% of finer**
20	0	0	0	100
12.5	142	14.2	14.2	85.8
10	220	22	36.2	63.8
4.75	510	51	87.2	12.8
0.6	95	9.5	96.7	3.3
0.15	10	1	97.7	2.3
Pan	20	2	99.7	0.3

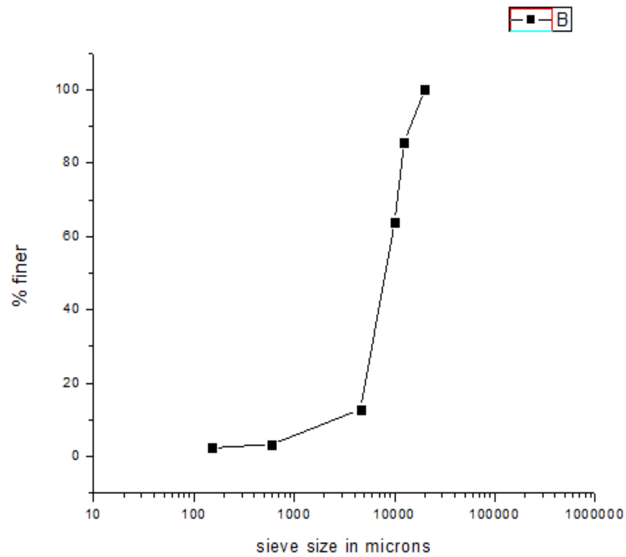

Fig 2 Particle size distribution for natural coarse aggregate

2.1.4 Recycled Fine Aggregate

The recycled fine aggregates are obtained from the crushed concrete aggregate passing through 4.75mm I.S sieve and are shown in Fig 3.

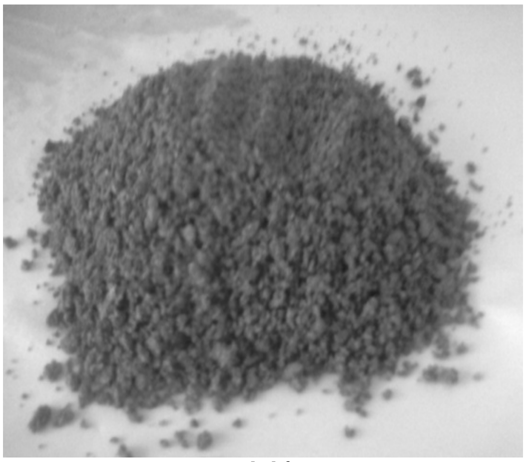

Fig 3 Recycled fine aggregate

a) Specific gravity

The test was conducted as per IS: 2386 (part III)-1963[3], and the value of specific gravity of recycled fine aggregate is 2.47.

Average value of specific gravity for recycled fine aggregate obtained is 2.47

b) Water absorption

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS 2386(Part 3)-1963[4]. The water absorption of recycled fine aggregate was obtained as 23.456%.

c) Sieve analysis

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregates and according to it grading of aggregates can be done. The sieve analysis is done as per IS 383-1970 [4]. The particle size distribution is shown in Table 4 and the Particle size distribution for recycled fine aggregate is shown in Fig 4.

Table 4 Sieve analysis of recycled fine aggregate

Sieve(mm)	Weight retained(g)	% of weight retained	Cumulative %weight retained	% of finer
10	0	0	0	100
4.75	0	0	0	100
2.36	360	36	36	64
1.18	281	28.1	64.1	35.9
0.6	148	14.8	78.9	21.1
0.3	113	11.3	90.2	9.8
0.15	94	9.4	99.6	0.4
Pan	4	0.4	100	0

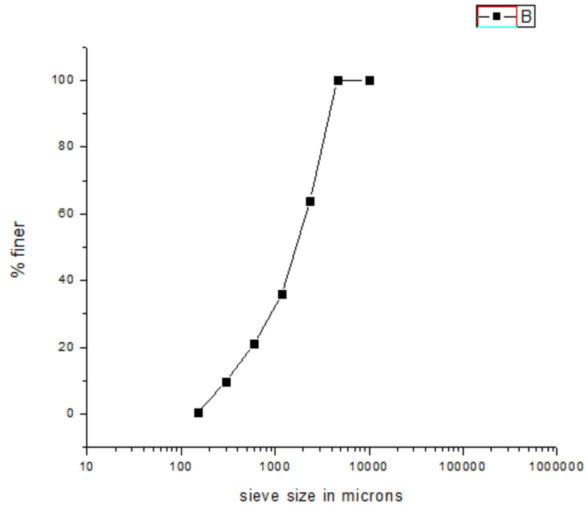

Fig 4 Particle size distribution for recycled fine aggregate

2.1.5 Recycled Coarse Aggregate

Crushed concrete aggregate waste passing through 12mm and retained on 4.75mm I.S sieve were used as recycled coarse aggregate as shown in Fig 5 and they meet the grading requirements.

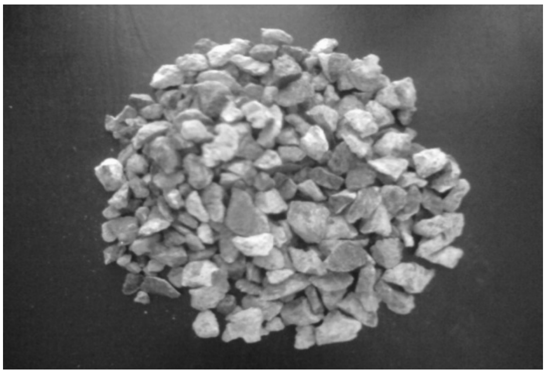

Fig 5 Recycled coarse aggregate

a) Specific gravity

The test was conducted as per IS: 2386 (part III)-1963[3], and the average value of specific gravity of recycled coarse aggregate is 2.339.

b) Water absorption

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. The water absorption of the natural coarse aggregates is found according to IS: 2386 (Part 3) – 1963 [4] and is obtained as 5%.

c) Sieve analysis

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregates and according to it grading of aggregates can be done. The sieve analysis is done as per IS 383-1970 [4]. The particle size distribution is shown in Table 5 and the Particle size distribution of recycled coarse aggregate is shown inFig 6.

Table 5 Sieve analysis of recycled coarse aggregate

Sieve(mm)	Weight retained(g)	% of weight retained	Cumulative %weight retained	% of finer
20	0	0	0	100
12.5	140	14	14	86
10	212	21.2	35.2	64.8
4.75	514	51.4	86.6	13.4
0.6	93	9.3	95.9	4.1
0.15	11	1.1	97	3
Pan	28	2.8	99.8	0.2

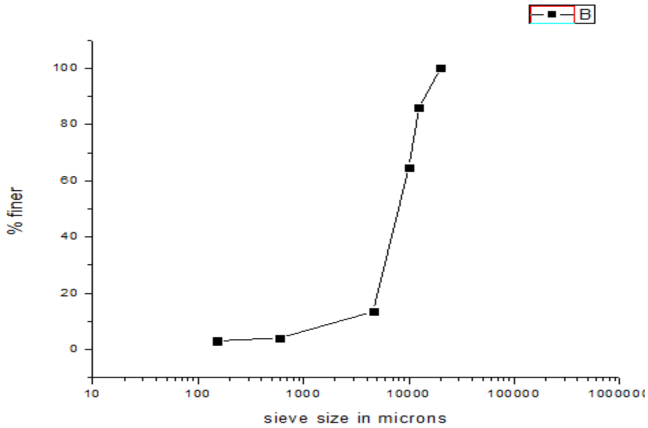

Fig 6 Particle size distribution of recycled coarse aggregate

2.1.6 Water

Portable water available in laboratory was used for mixing and curing the concrete specimens.

2.1.7 Pre Soaking Treatments

The recycled aggregates were crushed and soaked in water for 24 hours for water treatment then kept for drying.

2.2 Residual mortar content

Recycled aggregates are coated with cement mortar which is adhered to it. This mortar is referred to as residual mortar content. Percentage of this residual mortar content was experimentally found out. For this 1kg of oven dried RCA sample was taken and immersed in testing bath containing 26% sodium sulphate salt. Solution was made by mixing sodium sulphate salt and water well together until the full salt is dissolved in it. A sample was prepared and then placed in oven at 100^{o} C for a day time and placed in freezer in the evening till morning. The same procedure was repeated for 5 days. After alternate heating and cooling of sample for 5 days it was washed thoroughly under tap water by placing the sample in 4.75mm sieve. While washing it was noticed that the adhered mortar from RCA gets separated. The washed sample was kept in oven for 24 hours. The weight was taken after this. Experimental set up for the test is as shown in Fig 7.

Weight of oven dried sample taken (A) = 1 kg
Weight of oven dried sample taken after testing(B)= 0.756 kg
Residual Mortar Content = $\frac{A-B}{A}$ x 100 (%) = 24.4 %


Fig 7 Sample after alternate heating and cooling for 5 days

3. Experimental Work and Tests

3.1 Mix Design:

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing is of two fold. The first object is to achieve the stipulated minimum strength. The second object is to make the concrete in the most economical manner .Cost wise all concretes depend primarily on two factors; namely cost of material and cost of labor.

Considerable need has been felt for formulating standard recommendation guidelines for proportioning of concrete mixes. The need has been further emphasized by the importance given to design mix concrete according to IS 456. The proportioning of concrete mix consist of determination of the quantities of respective ingredients necessary to produce concrete having adequate, but not excessive, workability and strength for a particular loading and durability for the exposure to which it is subjected. Emphasize is laid on making most economical use of available materials so as to produce concrete of the required attributes at the minimum cost. The assumption made in mix design is that the compressive strength of workable concrete is, by and large governed by the water cement ratio. Another most convenient relationship applicable to normal concrete is that for a given type, size and gradation of aggregate the amount of water determines its workability.

Cement and concrete sectional committee decided to evolve standard recommended guidelines for the mix design, it is furnished in IS 10262. However the standard does not debar the adoption of any other accepted method of mix design. This chapter describes the details of mix design carried out and detail of different specimens casted.

3.2 Design of control mix

3.2.1 Mix design of SB_1

Density of solid block required= 1800 kg/m^3 (IS 2185 (Part 1):2005)
Ratio = 1:3:6 (Cement: Fine aggregate: Coarse aggregate)
Sum = 10
Volume of solid block = 0.0015 m^3 (190mm x 90mm x 90mm)
w/c ratio = 0.5
Amount of cement = $\frac{1}{10}$ x 0.0015 x 1800 = 0.27 kg/m^3
Amount of fine aggregate = $\frac{3}{10}$ x0.0015x1800 = 0.81kg/m^3
Amount of coarse aggregate = $\frac{6}{10}$ x0.0015x1800= 1.62kg/m^3
Amount of water = 0.5 x 0.27 = 0.135 lit

3.2.2 Mix design for SB_2

Density of solid block required = 1800 kg/m^3 (IS 2185 (Part 1):2005)
Ratio = 1:4:8 (Cement: Fine aggregate: Coarse aggregate)
Sum = 13
Volume of solid block = 0.0015 m3 (190mm x 90mm x 90mm)
w/c ratio = 0.5
Amount of cement = $\frac{1}{13}$ x 0.0015 x 1800 = 0.207 kg/m^3
Amount of fine aggregate = $\frac{4}{13}$ x 0.0015 x 1800 = 0.830 kg/m^3
Amount of coarse aggregate = $\frac{8}{13}$ x 0.0015 x 1800 = 1.66 kg/m^3
Amount of water = 0.5 x 0.207 = 0.103 lit

3.3 Determination of compressive strength

The main aim was to determine the compressive strength of solid blocks prepared with NCA and RFA. The test specimens are of size 190 x 90 x 90 mm. for each mix three blocks were cast and compression test was done after 28 days curing. Compaction was done using table vibrator. The block for testing was placed in the compression testing apparatus. The compressive strength was obtained by dividing the ultimate applied load by the cross- sectional area of the cube.

3.4 Determination of block density

Two blocks were taken at random from the samples selected and then dried to constant mass in an oven heated to approximately 100^{o}C. After cooling the blocks to room temperature the dimensions of each block was measured in centimeters and the overall volume computed in cubic centimeters. The blocks shall be weighed in kilograms and the density of each block can be calculated as per equation 1.

$$\text{Density} = \frac{\text{Mass of block in kg}}{\text{Volume of specimen in cm3}} \times 10^6 \text{ kg/m}^3 \qquad \text{.......... Equation 1}$$

The average of different trials are then determined

3.5 Determination of water absorption

The test specimens were completely immersed in water at room -temperature for 24 h. The specimens were then weighed, while being suspended by a metal wire and completely submerged in water. They were then removed from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth and immediately weighed. Subsequent to saturation, all specimens were them dried in a ventilated oven at 100^{0}C to 115°C for not less than 24 h and until two successive weightings at intervals of 2 h show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen. The water absorption was obtained using equation 2 or equation 3.

$$\text{Water absorption in kg/m}^3 = \frac{A-B}{A-C} \times 1000 \text{...........Equation 2}$$

$$\text{Water absorption in percentage} = \frac{A-B}{B} \times 100 \text{........... Equation 3}$$

Where,

A = wet mass of unit, in kg
B = dry mass of unit, in kg
C = suspended immersed mass of units, in kg.

The average of two blocks shall be taken as average value for water absorption.

3.6 Determination of moisture movement

The specimens shall be immersed in water for 4 days, the temperature being maintained at 27 ± 2°C for at least 4 h prior to the removal of the specimen and the wet length measured. The moisture movement shall be determined as the difference between the dry and wet lengths and expressed as a percentage of the dry length for each specimen.

4. Result and Discussion

4.1 Compressive strength test

The compressive strength of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the solid concrete blocks are used as load bearing units and shall have a block density not less than 1 800 kg/m^3 and these shall be manufactured for minimum average compressive strength of 4.0 and 5.0 N/mm^2 respectively. The results of compression test are given in Table 6

Table 6 Average compressive strength in 28 days

MIX ID	AVERAGE COMPRESSIVE STRENGTH IN 28 DAYS (N/mm^2)
SB1	8.771
SB2	8.596
SB3	8.070
SB4	7.309
SB5	6.905

SB6	6.432
SB7	6.257
SB8	5.555
SB9	5.380
SB10	4.912

Compressive strength of solid blocks with NCA and RCA was compared and it was found that the blocks cast using Natural Coarse aggregate and Natural Fine aggregate showed higher strength as compared to the one cast using Recycled Coarse aggregate and Recycled Fine aggregate.

4.2 Block density

The block density of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the solid concrete blocks shall have a block density not less than 1 800 kg/m^3. The results of the test are given in Table 7.

Table 7 Density values for the samples

MIX ID	DENSITY (kg/m^3)
SB1	2331.491
SB2	2119.53
SB3	1991.93
SB4	2129.30
SB5	2048.88
SB6	1907.58
SB7	2013.56
SB8	1978.23
SB9	1937.24
SB10	1907.58

Block density of solid blocks with NCA and RCA was compared and it was found that the blocks cast using Natural Coarse aggregate and Natural Fine aggregate showed higher strength as compared to the one cast using Recycled Coarse aggregate and Recycled Fine aggregate.

4.3 Water absorption

The water absorption of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the water absorption, being the average of two units shall not be more than 10 percent by mass.The results of the test are given in Table 8

Table 8 Water absorption values for the sample

MIX ID	WATER ABSORPTION (%)
SB1	6.06
SB2	6.66
SB3	5.51
SB4	7.290
SB5	7.068
SB6	7.280
SB7	7.50
SB8	7.068
SB9	7.507
SB10	8.079

Water absorption of solid blocks with NCA and RCA was compared and it was found that the blocks cast using Natural Coarse aggregate and Natural Fine aggregate showed higher strength as compared to the one cast using Recycled Coarse aggregate and Recycled Fine aggregate.

4.4 Moisture movement

The moisture movement of solid blocks with NCA as well as with RCA was determined. The moisture movement of the dried blocks on immersion in water, being the average of two units, shall not exceed 0.09 percent. The results of the test are given in Table 9

Table 9 Moisture movement values for the sample

MIX ID	MOISTURE MOVEMENT (%)
SB1	0.016
SB2	0.016
SB3	0.012
SB4	0.012
SB5	0.016
SB6	0.016
SB7	0.016
SB8	0.016
SB9	0.012
SB10	0.016

Moisture movement of solid blocks with NCA and RCA was compared and it was found that the blocks cast using Natural Coarse aggregate and Natural Fine aggregate showed higher strength as compared to the one cast using Recycled Coarse aggregate and Recycled Fine aggregate.

5. Conclusions

The following conclusions were drawn from the present study.

1. From the compression test it was found that SB2 has strength almost equal to 98% of concrete block with natural aggregate.
2. From the block density test it was found that the solid blocks were within the IS limit and it was obtained that the density of SB2 was 90% as that

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of SB1. SB4 has highest block density, and equal to 91% of SB1, The solid blocks were within the IS limit for the water absorption test from which it was obtained that SB1 has a water absorption less as compared to other samples in which NCA was replaced with RCA and NFA was replaced with RFA and residual mortar values were also incorporated.

3. From the moisture movement test it was obtained that all the specimens confirmed to IS specification and the values obtained was less than 0.09%.

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