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Experimental Investigations on Use of C&D Waste as an Alternative to Natural Aggregates in Concrete

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ABSTRACT. *An abstract summarizes, in one paragraph (usually), the major aspects of the entire paper in the following prescribed sequence. Construction and Demolition (C&D) waste constitutes a major portion of total solid waste produced across the globe, and most of this C&D waste is used in landfills. Research work in area of utilization of C&D waste indicates that after giving appropriate treatment, C&D waste can be utilized as a partial replacement of conventional aggregate in new concrete, especially in lower-level applications. This paper briefly discusses present provisions in Indian and international codes for use of C&D waste as recycled aggregates (RA) and recycled concrete aggregates (RCA) in plain and reinforced concrete. In present study, C&D waste collected from a demolished building and C&D waste processing plant in New Delhi was processed and classified in different fractions (as fine and coarse aggregates). Aggregates were characterized for their different physical and chemical characteristics and results were found to comply with present IS: 383 specifications. Concrete mixes were prepared by replacing natural coarse and fine aggregates with different proportions (up to 100%) of Recycled aggregates from both the sources. All the concrete mixes were evaluated for different fresh (workability and air content), hardened (compressive strength, flexural strength and Modulus of elasticity) and durability parameters (RCPT, drying shrinkage and water permeability) at various ages.*

Keywords: Construction and Demolition waste, Recycled aggregate, Characterization, Durability, Specifications

1. INTRODUCTION

Since the beginning of 21st century, world has witnessed rapid urbanization and industrialization leading to large scale consumption of natural resources by the construction industry [1]. Development of country mainly depends on the availability of infrastructure and concrete as a building material plays a vital role in the construction of this infrastructure. Concrete is mainly primarily composed of cement, aggregate (coarse and fine), water and chemical admixture. Worldwide consumption of concrete is estimated to be about 11.5 billion tons per year and by year 2050 it is expected to reach to 18 billion tons of concrete per year [2]. Such massive use of concrete in infrastructure projects can lead to serious environmental threats towards the resource conservation. In order to achieve sustainability in construction industry, use of alternate materials should be focussed with comprehensive approach. Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development. Continuous industrial development poses serious problems of construction and demolition waste disposal [3]. Whereas on the one hand, there is critical shortage of natural aggregates for production of new concrete, on the other the enormous amounts of demolished concrete produced from deteriorated and obsolete structures creates severe ecological and environmental problem [4, 5]. One of the ways to solve this problem is to use this 'waste' concrete (Construction and Demolition waste) as aggregates [6]. Construction and demolition (C&D) waste is defined as the solid waste generated by the construction, repair, alteration, or demolition of residential, commercial, or institutional buildings and infrastructures such as roads, bridges, dams, tunnels, railways, and airports. Research work carried out in several countries has demonstrated sufficient promise for developing use of C&D waste as a constituent (partial replacement of conventional coarse and fine aggregate) in new concrete. Recycled Aggregate (RA) coming from the concrete obtained from demolition of buildings, bridge supports, airport runways, and concrete roadbeds is referred as recycled concrete aggregate (RCA) [7]. The main reasons for continuous increase in volume of demolition concrete / masonry waste are as follows: -

i. Many old buildings, concrete pavements, bridges, and other structures have overcome their age and limit of use due to structural deterioration beyond repairs and need to be demolished.
ii. The structures, even adequate to use are under demolition because they are not serving the needs in present scenario.
iii. New construction for better economic growth.
iv. Structures are turned into debris resulting from natural disasters like earthquake, cyclone, and floods etc.
v. Creation of building waste resulting from manmade disaster/war.

The physical and mechanical properties of recycled concrete aggregates (RCA) obtained from C&D waste will not be similar to the original aggregates with which old concrete structure was built. These differences in physical and mechanical properties of recycled concrete aggregate can be attributed to the patches of cement mortar present after crushing which increases the water absorption of the RCA and will affect the strength of the new concrete made with RCA. Mortar present on recycled aggregate varies from 40 to 60% depending upon the size of the aggregates and the water absorption lies between 3–10 percent. Higher water absorption of recycled aggregate will have effect on compressive strength, resistance to freezing and thawing, elasticity, creep, shrinkage, and workability of concrete [8]. Inclusion of recycled aggregate [9] decreased the permeability of concrete mixes. Chloride conductivity increases with increased percentage of recycled aggregate. It also results in decreased workability and loss of slump in a short time. Studies on durability parameters of concrete made with recycled concrete aggregates obtained from C&D waste are still very limited.

In view of the above mentioned studies, it becomes imperative to conduct systematic studies on detailed classification and characterization of recycled concrete aggregates (obtained from C&D waste) and evaluate the performance of concrete mixes containing coarse and fine recycled concrete aggregates as a replacement of natural aggregates in concrete and compare their performance with corresponding control concrete mixes made with 100% natural aggregates in terms of different fresh, hardened and especially durability properties of concrete, as very limited studies has been conducted on the durability parameters of concrete made with recycled concrete aggregates as a replacement of natural aggregates so as to enable use of C&D waste as a part replacement of natural aggregate in concrete.

2. INCORPORATION IN SPECIFICATIONS

The specific provisions pertaining to use of recycled concrete aggregates (both coarse and fine) obtained from C&D waste in present codes of different countries are as discussed below:

2.1 IS: 383, included in draft revision

It states that recycled fine and coarse aggregate can be used as replacement of Natural aggregate up to 25% in case of Plain concrete and up to 20% for M20 grade of reinforced concrete. It is not permitted to use recycled aggregate for more than M20 Grade of reinforced concrete.

Table-1: Additional requirements for manufactured aggregate [10]

Sl. No.	Characteristics	Requirement
1.	Total alkali content as Na_2O equivalent, percent, Max	0.3
2.	Sulphate content as SO_3, percent, Max	0.02
3	Chloride Content, percent, Max	0.04
4	Water absorption, percent, Max	10*
5.	Specific Gravity	2.1 to 3.2

Higher Water Absorption is permitted subject to pre-wetting (saturation) of aggregate before batching and mixing.

2.2 European (CEN) Practice – EN 12620 [11]

Evaluation of physical properties like bulk density, water absorption, freeze thaw resistance, drying shrinkage, soundness, alkali silica reactivity of RCA is mandatory. Similarly, evaluation of chemical properties like chloride, acid soluble sulphate, sulphur content and carbonate content of RCA is mandatory.

2.3 UK - BS 8500-2:2006, [12]

This standard, which is the complementary British Standard to BS EN 206, refers to two types of recycled aggregate namely, recycled concrete aggregate (RCA), and Recycled aggregate (RA). RCA is obtained from crushing demolished concrete structures, discarded precast elements and unused hardened concrete. In some modification of EN 12620, BS 8500 stipulates that RCA must be predominantly composed of concrete (at least 83.5 percent) and masonry content not more than 5 percent. Such aggregate can be used in structural concrete having cube strength of concrete 50 MPa. Recycled aggregate concrete containing crushed leftover concrete has no strength limitation provided the aggregate is not contaminated. For concrete cube strengths of 25 to 50 MPa, a maximum of 20 percent replacement of coarse aggregate applies, for designated concrete.

RA may contain masonry up to 100 percent. Because the potential composition of recycled aggregate (RA) is so wide, additional specification clauses may be required on a case-by-case basis. A project specification should include maximum acid soluble sulphate, method for determining the alkali content, ASR reactivity and any limitations on use in concrete. Recycled aggregate (RA) is limited to concrete cube strength of 20 MPa.

Similarly, other Countries like USA, Germany, Norway, Japan etc. are also using C&D waste as a replacement of natural aggregate.

3. COLLECTION OF C&D WASTE

The C&D waste was taken from a demolished building in New Delhi and a plant situated in Delhi, India (Figure-1). In the processing facility, IL&FS Environmental Infrastructure & Services Ltd (IEISL) collected 500 tonne per day (TPD) of C&D waste from three designated zones of the Delhi.

Fig -1: C&D Waste Plant at Delhi, India

4. EXPERIMENTAL WORK

As discussed earlier, the C&D waste for this study was collected from a demolished building in New Delhi and a C&D waste plant situated in Delhi, India. Construction and Demolition waste from each location was processed and classified in different fractions as recycled coarse and fine aggregates at NCCBM laboratory. Further, aggregates obtained from C&D waste collected from both sites were evaluated for different physical (such as specific gravity, water absorption, sieve analysis, silt content, impact value, crushing value, Los Angeles Abrasion value, soundness, elongation and flakiness index) and chemical properties (total alkali content as Na_2O equivalent, Sulphate content as SO_3 and Chloride content) as per IS: 2386 [13]. Apart from recycled aggregates obtained from C&D waste, natural coarse and fine aggregates used in this study were also evaluated for different physical properties (as in the case of recycled aggregates). Cement (PPC) used in this study for preparation of concrete mixes was also characterized for its physical and chemical characteristics as per relevant Indian standards.

Control concrete mix (M-NA) was prepared using PPC along with 100% natural fine aggregates and 100% natural coarse aggregates at water-cement ratio of 0.55. Then, mixes were prepared by replacing 25, 50, 75 and 100% natural fine aggregates with recycled fine aggregates from demolished building (D) and recycled fine aggregate from C&D waste plant (R) along with 100% natural coarse aggregates at water to cement ratio of 0.55. Further, mixes were prepared by replacing 25, 50, 75 and 100% natural coarse aggregate with recycled coarse aggregates from demolished building (Y) and recycled coarse aggregate from C&D waste plant (X) at along with 100% natural fine aggregates at water to cement ratio of 0.55.

Thus, a total number of 17 concrete mixes were prepared. All the mixes were studied for fresh properties of concrete such as workability (in terms of slump) and air content of concrete as per IS: 1199 [14]. Further, mixes were evaluated for different mechanical properties such as compressive strength and flexural strength at 7, 28, 56 and 90 days. Mixes were also studied for different durability properties of concrete tests such as Rapid Chloride ion penetrability test (RCPT), drying shrinkage, water permeability and Modulus of Elasticity.

5. CHARACTERIZATION OF RECYCLED FINE AND COARSE AGGREGATES FROM BOTH LOACTION ALONG WITH NATURAL AGGREGATES AND PPC USED IN STUDY

5.1 Characterization of Natural Coarse and fine aggregates

Natural Coarse aggregates with a maximum nominal size of 20 mm and natural fine aggregates conforming to Zone III as per IS 383:2016 [15] were used in this study for preparation of control concrete mix. Results of characterization of natural coarse and fine aggregates have been tabulated in table 2.

Table -2: Characterization results of Natural coarse and fine aggregates

Property		**Natural Fine Aggregate**	**Natural Coarse Aggregate**	
			20 mm	**10 mm**
Specific gravity		2.64	2.81	2.8
Water absorption (%)		0.6	0.4	0.4
Sieve Analysis Cumulative Percentage Passing (%)	20mm	100	97	100
	10 mm	100	1	95
	4.75 mm	100	0	9
	2.36 mm	100	0	0
	1.18 mm	97	0	0
	600 µ	74	0	0
	300 µ	25	0	0
	150 µ	05	0	0
Silt Content, By wt (%)		2.1		
Impact Value, %			20	
Crushing Value, %			18	
Los Angeles Abrasion, %			23	
Soundness, Na2SO4, %		1.7	2.2	
Elongation Index, %			14	
Flakiness Index %			5	
CBD, kg/m^3		1580	1630	
LBD, kg/m^3		1410	1470	

5.2 Characterization of Recycled Coarse and fine aggregates

Construction and Demolition waste from both locations (demolished building and C&D waste plant) was processed and classified in different fractions as recycled coarse and fine aggregates at NCCBM laboratory. Results of physical and chemical characterization of recycled fine aggregates obtained from demolished building (D) and recycled coarse aggregates (20 mm and 10 mm) from demolished building (Y) as per IS 383: 2016 have been tabulated in table 3 and 4 below.

Table -3: Physical Properties of Recycled aggregates obtained from C&D waste of demolished building

Property	**Recycled Fine Aggregate from demolished building (D)**	**Recycled coarse aggregates from demolished building (Y)**

			20 mm	10 mm
Specific gravity		2.12	2.17	2.16
Water absorption (%)		8.2	6.7	6.5
Sieve Analysis Cumulative Percentage Passing (%)	20mm	100	100	100
	10 mm	100	7	100
	4.75 mm	100	1	11
	2.36 mm	96	0	0
	1.18 mm	88	0	0
	600 µ	68	0	0
	300 µ	28	0	0
	150 µ	14	0	0
Silt Content, By wt (%)		8.0		
Impact Value, %			34	
Crushing Value, %			36	
Los Angeles Abrasion, %			47	
Soundness, Na2SO4, %		4.5	4.1	
Elongation Index, %			23	
Flakiness Index %			7	
CBD, kg/m^3		1070	1160	
LBD, kg/m^3		1120	1070	
Mortar Content		61%	24%	45%

Table -4: Chemical Properties Recycled aggregates obtained from C&D waste of Demolished Building in Delhi

Sl. No	Characteristic	Recycled coarse aggregates from demolished building (Y)	Recycled Fine Aggregate from demolished building (D)	Requirement as per IS 383: 2016
1	Total Alkali Content as Na_2O equivalent, %	3.8	3.3	Max, 0.3%
2	Sulphate Content as SO_3 (%)	0.22	0.25	Max, 0.5%
3	Chloride Content, %	0.52	0.65	Max, 0.04%

The results of physical properties of recycled fine aggregates and recycled coarse aggregates from demolished building (D & Y) shows that specific gravity of recycled aggregate samples was observed to be lower than that of natural aggregates due to presence of adhered mortar. Due to presence of mortar, water absorption was quite high in comparison to natural aggregates. The chemical properties of recycled fine aggregates and recycled coarse aggregates from demolished building (D & Y) meet the requirements of sulphate content as per IS: 383-2016. However, the alkali content and chloride content exceed the recommended limits. Therefore, these aggregates shall be recommended for use in Plain Cement Concrete (PCC), Dry Lean Concrete (DLC) and low volume traffic concrete roads only. Such aggregates shall not be recommended for use in Reinforced Cement Concrete (RCC) and mass concrete where they can lead to long term undesirable phenomena such as chloride induced reinforcement corrosion and alkali aggregate reaction respectively.

Like above, recycled fine aggregates obtained from C&D waste plant (R) and recycled coarse aggregates (20 mm and 10 mm) obtained from C&D waste plant (X) were characterized for different physical and chemical properties as per IS 383: 2016. Results have been tabulated in table 5 and 6 below.

Table -5: Physical Properties of Recycled aggregates obtained from C&D waste of C&D waste Plant in New Delhi

Property		Recycled Fine Aggregate from C&D waste plant (R)	Recycled coarse aggregates from C&D waste plant (X)	
			20 mm	10 mm
Specific gravity		2.1	2.36	2.35
Water absorption (%)		9.1	5.1	5.4
Sieve Analysis Cumulative Percentage Passing (%)	20mm	100	98	100
	10 mm	100	3	90
	4.75 mm	100	0	28

	2.36 mm	95	0	5
	1.18 mm	84	0	0
	600 µ	65	0	0
	300 µ	30	0	0
	150 µ	18	0	0
Silt Content, By wt (%)		9.8		
Impact Value, %			25	
Crushing Value, %			29	
Los Angeles Abrasion, %			35	
Soundness, Na2SO4, %		4.23	2.8	
Elongation Index, %			14	
Flakiness Index %			3	
CBD, kg/m^3		1180	1380	
LBD, kg/m^3		1230	1290	
Mortar Content		52%	20%	42%

Table -6: Chemical Properties Recycled aggregates obtained from C&D Waste of C&D waste Plant, New Delhi

Sl. No	Characteristic	Recycled coarse aggregates from C&D waste plant (X)	Recycled Fine Aggregate from C&D waste plant (R)	Requirement as per IS 383: 2016
1	Total Alkali Content as Na_2O equivalent, %	2.7	2.1	Max, 0.3%
2	Sulphate Content as SO3, %	0.19	0.11	Max, 0.5%
3	Chloride Content, %	0.32	0.45	Max, 0.04%

Similar to results of recycled aggregates obtained from demolished building, the results of physical properties of recycled fine aggregates and recycled coarse aggregates from C&D waste plant (R & X respectively) shows that specific gravity of slag samples was observed to be lower than that of natural aggregates due to presence of adhered mortar. Due to presence of mortar, water absorption was quite high in comparison to natural aggregates. Similar to chemical properties of recycled aggregates obtained from demolished building (D & Y), the chemical properties of recycled fine aggregates and recycled coarse aggregates from C&D waste plant (X & R) meet the requirements of sulphate content as per IS: 383-2016. However, the alkali content and chloride content exceed the recommended limits. Therefore, these aggregates shall be recommended for use in Plain Cement Concrete (PCC), Dry Lean Concrete (DLC) and low volume traffic roads only. Such aggregates shall not be recommended for use in Reinforced Cement Concrete (RCC) and mass concrete where they can lead to long term undesirable phenomena such as chloride induced reinforcement corrosion and alkali aggregate reaction respectively.

5.3 Characterization of PPC

PPC used for preparation of concrete mixes along with natural and recycled aggregates was evaluated for different physical and chemical properties as per IS 1489 (Part 1): 1991 [16]. Results of physical and chemical characteristics of PPC has been tabulated in table 7.

Table -7: Physical and Chemical Characteristics of PPC

Physical Properties	**PPC**
Fineness Blaine's (m^2/kg)	356
Soundness Autoclave (%)	0.06
Soundness Le Chatelier's (%)	2
Setting Time Initial (min.)	155
Setting Time Initial (max.)	215
Compressive Strength, 72±1 hrs, MPa	24.5
Compressive Strength, 168±2 hrs, MPa	32
Compressive Strength, 672±4 hrs, MPa	43
Specific gravity	2.89
Chemical Properties	
Loss of Ignition (LOI) (%)	2.74
Silica (SiO_2) (%)	32.2

Iron Oxide (Fe_2O_3) (%)	3.57
Aluminium Oxide (Al_2O_3)	10.84
Calcium Oxide (CaO) (%)	43.42
Magnesium Oxide (MgO) (%)	1.35
Sulphate (SO_3) (%)	2.15
Alkalies (%) Na_2O	0.89
Alkalies (%) K_2O	0.53
Chloride (Cl) (%)	0.05
IR (%)	23.16

6. STUDIES ON FRESH, HARDENED AND DURABILITY PROPERTIES OF CONTROL AND EXPERIMENTAL CONCRETE MIXES

6.1 Mix design details

Control concrete mix (M-NA) was prepared using PPC along with 100% natural fine aggregates and 100% natural coarse aggregates at water-cement ratio of 0.55. Mix details of control concrete mix has been given in table 8. All the mixes (control and experimental mixes) were designed and prepared at same water to cement ratio of 0.55 (not designed for particular grade) using Naptha based superplasticizer (BASF Rheobuild 1100). Further, the mechanical and durability properties of experimental concrete mixes thus prepared, were compared with corresponding properties of control concrete mix.

Table -8: Concrete Mix Design Details of control mix (M-NA)

Sl. No.	W/C	Mix Constituents				Fine Aggregate as % of Total Aggregate by weight	28-Days strength of concrete (N/mm^2)
		Cement	Cement Content (Kg/m^3)	Water Content (Kg/m^3)	Dose of Admixture % by weight of Cement		
Exposure Condition: Moderate							
1	0.55	PPC	300	165	1.2	35	24.36

Then, experimental concrete mixes were prepared by replacing 25, 50, 75 and 100% natural fine aggregates with recycled fine aggregates from demolished building (D) [namely M-D25, M-D50, M-D75 & M-D100] and recycled fine aggregate from C&D waste plant (R) [namely M-R25, M-R50, M-R75 & M-R100] along with 100% natural coarse aggregates at water to cement ratio of 0.55.

Further, experimental concrete mixes were prepared by replacing 25, 50, 75 and 100% natural coarse aggregate with recycled coarse aggregates from demolished building (Y) [namely M-Y25, M-Y50, M-Y75 & M-Y100] and recycled coarse aggregate from C&D waste plant (X) [namely M-X25, M-X50, M-X75 & M-X100] along with 100% natural fine aggregates at water to cement ratio of 0.55.

For experimental concrete mixes, appropriate adjustment was made in quantity of mixing water to account for higher water absorption of recycled aggregates. The laboratory conditions were monitored during the curing i.e. temperature of 27±2°C and relative humidity of 65±5% was maintained.

6.2 Fresh Concrete Properties

Fresh concrete properties such as workability (in terms of slump) after preparation of mix and air content as per IS 1199 were evaluated for all the 17 mixes and test results are given in Table 9.

Table -9: Fresh concrete properties of control and experimental mixes

Specimen ID	% Replacement of natural aggregates with recycled aggregates	Workability in terms of slump (mm)	Air Content %	Specimen ID	% Replacement of natural aggregates with recycled aggregates	Workability In terms of slump (mm)	Air Content %
M-NA	**0**	**85**	**2.0**	**M-NA**	**0**	**85**	**2.0**
M-D25	25	75	1.8	M-Y25	25	85	2.2
M-D50	50	65	1.6	M-Y50	50	80	2.2

M-D75	75	50	1.3	M-Y75	75	75	2.3
M-D100	100	40	1.1	M-Y100	100	70	2.4
M-R25	25	70	1.7	M-X25	25	80	2.1
M-R50	50	60	1.5	M-X50	50	80	2.2
M-R75	75	50	1.3	M-X75	75	75	2.3
M-R100	100	30	1.2	M-X100	100	70	2.5

NOTE:

1. D: Recycled fine aggregate from demolished building,
2. R: Recycled Fine Aggregate from C&D waste plant
3. Y: Recycled Coarse aggregate from demolished building
4. X: Recycled Coarse Aggregate from C&D waste plant

Concrete mixes containing higher percentage of recycled fine aggregates (D & R) from both the sources showed lower slump in comparison to the control concrete mix due to mortar present on the surface of recycled aggregates. However, marginal reduction in slump was observed in case of experimental concrete mixes containing coarse recycled aggregates (Y & X) with slightly higher air content.

6.3 Hardened Concrete Properties

Hardened concrete properties were evaluated for all the seventeen concrete mixes. Compressive strength test (as shown in figure 2) was conducted on concrete cubes (size 150 mm) as per IS: 516 [17]. Flexural strength test (as shown in figure 3) was conducted on concrete beam (size 500mm x 100mm x 100mm) as per IS: 516. Both compressive and flexural strength tests were conducted at age of 7, 28, 56 and 90 days. The test results of compressive and flexural strength are tabulated in table 10 and 11.

Fig -2: Test Set up for Compressive Strength Test

Fig -3: Sample undergoing Flexural Strength Test

Table -10: Compressive and flexural strength of concrete mixes containing different percentages of recycled fine aggregates (D & R) as a replacement of natural fine aggregate along with 100% natural coarse aggregate

Specimen ID	% Replacement of natural fine aggregates with recycled fine aggregates	Compressive Strength (MPa)				Flexure Strength (MPa)			
		07 Days	28 Days	56 Days	90 Days	07 Days	28 Days	56 Days	90 Days
M-NS	**0**	**16.205**	**24.36**	**32.96**	**37.14**	**1.79**	**2.98**	**3.79**	**4.36**
M-D25	25	20.34	27.32	37.74	43.64	2.01	3.23	4.04	4.62
M-D50	50	22.65	29.47	39.78	44.79	2.13	3.37	4.28	4.86
M-D75	75	19.32	25.06	34.17	39.60	2.03	3.10	3.98	4.40
M-D100	100	15.7	23.26	31.90	37.20	1.88	2.80	3.60	4.02
M-R25	25	19.901	26.81	36.54	42.00	1.97	3.14	3.95	4.58

M-R50	50	21.42	28.84	38.48	44.16	2.09	3.26	4.13	4.71
M-R75	75	19.096	24.92	33.68	38.30	2.01	3.04	3.86	4.30
M-R100	100	15.484	23.73	31.73	36.64	1.93	2.71	3.47	3.92

Table -11: Compressive and flexural strength of concrete mixes containing different percentages of recycled coarse aggregates (Y & X) as a replacement of natural coarse aggregates along with 100% natural fine aggregate

Specimen ID	**% Replacement of natural coarse aggregates with recycled coarse aggregates**	**Compressive Strength (MPa)**				**Flexure Strength (MPa)**			
		07 Days	28 Days	56 Days	90 Days	07 Days	28 Days	56 Days	90 Days
M-NS	0	16.205	24.36	32.96	37.14	1.79	2.98	3.79	4.36
M-Y25	25	16.94	28.15	37.14	39.67	2.13	3.33	4.1	4.74
M-Y50	50	15.9	24.35	32.45	36.89	1.88	3.15	3.88	4.43
M-Y75	75	14.68	22.98	29.93	32.76	1.7	2.75	3.56	4.2
M-Y100	100	13.64	20.49	26.78	29.9	1.61	2.52	3.35	4.04
M-X25	25	16.425	27.8	36.85	39.49	2.1	3.3	4.01	4.67
M-X50	50	15.85	24.1	32.18	36.65	1.82	3.1	3.84	4.4
M-X75	75	14.25	22.76	29.67	32.5	1.67	2.71	3.52	4.17
M-X100	100	13.5	20.18	26.56	29.73	1.55	2.5	3.3	3.98

Compressive and flexural strength of experimental concrete mixes containing different percentages (25 to 100%) of recycled fine aggregates (D & R) as a replacement of natural fine aggregate is either higher or comparable to control concrete mixes at all the ages. However, in case of experimental mixes containing recycled coarse aggregates (Y &X) as a replacement of natural coarse aggregates, compressive and flexural strength of experimental mixes are comparable to control, mix till replacement level of 50%. When natural coarse aggregates are replaced with recycled coarse aggregates by more than 50% (i.e. 75 & 100%), there is a reduction in compressive and flexural strength in comparison to control concrete mix.

6.4 Durability Properties of concrete mixes

Durability parameters were studied for all the control and experimental concrete mixes. Rapid Chloride ion penetrability test (RCPT) was conducted on concrete cylindrical disc (100mm diameter and 50mm thick) as per ASTM C-1202 [18]. Water permeability test (as shown in figure 5) was conducted on cubes of 150 mm size as per IS 516. Modulus of Elasticity was evaluated using concrete cylinder (150mm diameter and 300mm height) as per IS 516. Drying shrinkage test was conducted on concrete beam (75 x 75 x 300 mm) as per IS: 1199.

6.4.1. Rapid chloride ion permeability test (RCPT): This test (as shown in figure 4) is used to evaluate the concrete against the chloride ion penetration as per ASTM C 1202. This test had been conducted on saturated 50mm thick concrete slice of 100mm diameter extracted from the concrete specimen (of diameter =100mm and length=200mm) during each cycle of testing. A potential difference of 60V DC was maintained across the ends of the specimen, one end (which is exposed to 5 bars of hydraulic pressure) immersed in 3.0% NaCl solution and the other end in 0.3M NaOH solution. The total charge passed (in coulombs) through samples of various grades at the age of 28 days has been given in table 12 and 13.

Fig -4(a): Vacuum box and **4 (b):** DC voltage system for RCPT tests

6.4.2. Modulus of Elasticity: This property is conventionally measured using standardized tests based on small specimens subjected to uniaxial compressive loading. The Modulus of Elasticity was determined (as shown in figure 5) on cylindrical samples of 150 mm diameter and 300 mm height as per IS: 516. The concrete specimens were tested in a strain-controlled compression testing machine with 3000 KN capacity (Figure-2) at room temperature of 27±2ºC and relative humidity 65% or more. Two extensometers at the middle half of the height were used to get strain and two strains were averaged. The test results are given in Table 12 and 13.

Fig 5: Test setup for Modulus of Elasticity of concrete in Strain Controlled Machine

6.4.3. Water permeability test: The water permeability test was carried out at the age of 28 days on cubical specimen of size 150 mm as per IS 516 as shown in figure 6. The test results are given in Table 12 and 13.

Fig -6: Test Setup for Water permeability test

6.4.4. Drying Shrinkage: The drying shrinkage test was carried out at the age of 28 days on prism specimen of size 75×75×300 mm as per IS: 1199 as shown in figure 7. In this method change in length of concrete specimens due to changes in moisture content was measured. The “drying shrinkage” was calculated as the difference between the “original wet measurement” and the “dry measurement” expressed as a percentage of the "dry length". The drying shrinkage, probably the most significant contributor to macroscopic dilation and it is caused by the migration of water from pores and capillaries. The test results are given in Table 12 and 13.

Fig -7: Test set up for Drying Shrinkage Test as per IS: 1199

Table -12: Durability test results of concrete mixes containing different percentages of recycled fine aggregates (D & R) as a replacement of natural fine aggregate along with 100% natural coarse aggregate

Specimen ID	% Replacement of natural fine aggregates with recycled fine aggregates	RCPT, Coulomb's	Drying Shrinkage (%)	Water Permeability (mm)	Modulus of Elasticity (MPa)
		28 Days	28 Days	28 Days	28 Days
M-NS	0	1237	0.0182	22	27838
M-D25	25	1677	0.023	21	29010
M-D50	50	2062	0.025	18	29738
M-D75	75	2439	0.03	16	28960
M-D100	100	2632	0.035	12	26027
M-R25	25	1728	0.0221	20	28480
M-R50	50	2115	0.0247	17	29546
M-R75	75	2523	0.0286	15.5	28699
M-R100	100	2755	0.0325	14	25751

Table -13: Durability test results of concrete mixes containing different percentages of recycled coarse aggregates (Y & X) as a replacement of natural coarse aggregates along with 100% natural fine aggregate

Specimen ID	% Replacement of natural fine aggregates with recycled fine aggregates	RCPT, Coulomb's	Drying Shrinkage (%)	Water Permeability (mm)	Modulus of Elasticity (MPa)
		28 Days	28 Days	28 Days	28 Days
M-NS	**0**	**1237**	**0.0182**	**22**	**27838**
M-Y25	25	1730	0.024	26	28035
M-Y50	50	2340	0.027	27	24910
M-Y75	75	2865	0.032	28	22170
M-Y100	100	3120	0.037	30	19835
M-X25	25	1645	0.023	24	28010
M-X50	50	2280	0.026	25	24860
M-X75	75	2750	0.03	27	22090
M-X100	100	3020	0.035	29	19473

Performance in terms of RCPT, Water permeability and Modulus of Elasticity test for experimental concrete mixes containing different percentages (25 to 100%) of recycled fine aggregates (D & R) as a replacement of natural fine aggregate is either better or comparable to control concrete mixes as was in the case of compressive and flexural strength test results. However, in case of experimental mixes containing recycled coarse aggregates (Y &X) as a replacement of natural coarse aggregates, performance in terms of RCPT, Water permeability and Modulus of Elasticity test for experimental mixes are comparable to control mix till replacement level of 50%. When natural coarse aggregates are replaced with recycled coarse aggregates by more than 50% (i.e. 75 & 100%), there is a significant reduction in performance of experimental mixes in case of these three test in comparison to control concrete mix. Due to higher water absorption of recycled aggregate, the drying shrinkage of concrete increases with increase in recycled aggregate as compared to natural aggregate. Drying Shrinkage varies from 0.0182 to 0.035, i.e. the shrinkage gets doubled when using 100% recycled coarse aggregate in concrete as comparing to 0.0182% of natural aggregate.

7. CONCLUSIONS

Based on the results and observations of above-mentioned studies following conclusions can be drawn:

a) Physical characterization of recycled fine and coarse aggregates obtained from C&D waste collected from demolished building and C&D waste plant in New Delhi showed that specific gravity of recycled aggregate samples was lower than that of natural aggregates due to presence of adhered mortar. Due to presence of mortar, water absorption was quite high in comparison to natural aggregates. The chemical properties of recycled fine and coarse aggregates from both locations meet the requirements of sulphate content as per IS: 383-2016. However, the alkali content and chloride content exceed the recommended limits. Therefore, use of these aggregates shall be recommended for use in Plain Cement Concrete (PCC), Dry Lean Concrete (DLC) and low volume traffic roads only. Such aggregates shall not be recommended for use in Reinforced Cement Concrete (RCC) and mass concrete where they can lead to long term undesirable phenomena such as chloride induced reinforcement corrosion and alkali aggregate reaction respectively.

b) Concrete mixes containing higher percentage of recycled fine aggregates (D & R) from both the sources showed lower slump in comparison to the control concrete mix due to presence of mortar in recycled aggregates. However, marginal reduction in slump was observed in case of experimental concrete mixes containing different fractions of coarse recycled aggregates with slightly higher air content.

c) Compressive and flexural strength of experimental concrete mixes containing different percentages (up to 100%) of recycled fine aggregates as a replacement of natural fine aggregate is either higher or comparable to control concrete mixes at all the ages. However, in case of experimental mixes containing recycled coarse aggregates as a replacement of natural coarse aggregates, compressive and flexural strength of experimental mixes are comparable to control mix only till replacement level of 50%. When natural coarse aggregates are replaced with recycled coarse aggregates by more than 50% (i.e. 75 & 100%), there is a reduction in compressive and flexural strength in comparison to control concrete mix.

d) Performance of experimental concrete mixes containing different percentages (up to 100%) of recycled fine aggregates as a replacement of natural fine aggregate in terms of RCPT, Water permeability and Modulus of Elasticity test is either better or comparable to control concrete mixes. However, in case of experimental mixes containing recycled coarse aggregates as a replacement of natural coarse aggregates, performance in terms of RCPT, Water permeability and Modulus of Elasticity test for experimental mixes are comparable to control mix only till replacement level of 50%. When natural coarse aggregates are replaced with recycled coarse aggregates by more than 50% (i.e., 75 & 100%), there is a significant reduction in performance of experimental mixes in case of these three tests in comparison to control concrete mix.

e) Due to higher water absorption of recycled aggregate, the drying shrinkage of concrete increases with increase in recycled aggregate as compared to natural aggregate.

f) Based on the above studies, it can be concluded that there is scope for revision (increasing) of the current permissible limits in Indian Standards for utilization of recycled coarse and fine aggregates as replacement of conventional aggregates in concrete.

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