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Effect of Replacement of Natural Aggregates with Recycled Coarse Aggregates on Strength of Ternary Blended Cement Concrete

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Abstract

Replacement potential of recycled coarse aggregates in concrete has been at the forefront of research for many decades. It is now established that despite the quality of recycled coarse aggregates affecting the characteristics of RAC, compressive strength being one of the primary parameters, an equivalent concrete can still be produced. An effort is made through this paper to ascertain this fact that recycled coarse aggregates, when used in ternary blended cement concretes, are and can still be a viable alternative in structural concrete. The objective of the present investigation is to assess the compressive strength of concrete having both supplementary cementitious materials (fly ash and alccofine) and recycled coarse aggregates, homogeneously blended by adding a high range water reducing polycarboxylate ether based chemical admixture and recommend an optimum replacement of natural coarse aggregates with recycled coarse aggregates in the ternary blended cement concrete. In the present investigation, two different concrete grades of strengths 40MPa and 60MPa, were studied with different replacements of natural coarse aggregates by recycled coarse aggregates, having replacement ratios (Rr) 0, 0.2, 0.4, 0.5, 0.6, 0.8 & 1.0, for 7days and 28days compressive strengths. A total of 84 standard cube specimens were cast and tested. Based on the test results, it was observed that an equivalent M40 concrete can be achieved with Rr = 1.0 and we can safely replace natural coarse aggregates with recycled coarse aggregates up to Rr = 0.5, to get an equivalent M60 concrete.

Keywords: Blended Concrete, Replacement Ratio Rr, Recycled Coarse Aggregates, Compressive strength.

Introduction:

Depletion of natural resources due to rapid increase in infrastructural development across the globe, leading to generation of enormous volumes of construction debris over a period of time has paved the way for recycling of the construction wastes for various economies, especially those with limited resources. It is reported that for producing a tonne of natural aggregates, 0.0046 million ton of carbon is emitted as compared to a tonne of recycled aggregate which produces only 0.0024 million ton of carbon emissions.

Recycled concrete aggregates (RCA) can be obtained by crushing both reinforced and plain (non-rein forced) concrete and are produced in stationary recycling plants like those used for natural, crushed aggregate production. Processing usually includes two-stage crushing (primarily with jaw crushers and secondarily with impact crushers), removing the contaminants and screening. Recycled concrete aggregate is of particular benefit where construction is taking place on the site of former construction which comprises a high proportion of concrete (for example, frame, slabs or pavement). Recycled concrete aggregates have been widely used in road construction for sub-base and concrete pavements over many years but RCA application in concrete structures has still a few takers (8,12). Use of RCA in structural concrete shall make the construction green and environment friendly and large scale use may help to reduce the effects of the construction on these factors by reusing waste materials and preventing more natural aggregates from being harvested.

Recycled aggregates show more porosity and water absorption (9,10) associated with lesser density and strength compared to the conventional natural aggregates (7). RCA obtained from high-strength concrete is likely to have lower water absorption capacity (2, 4, 11). However, it has been found that the water absorption of RCA is independent of the compressive strength of the original concrete when the material is subjected to a sufficiently high number of processing stages (5). Thus, any concrete prepared with replacing natural aggregates with recycled aggregates tends to yield relatively reduced strength values as compared to that of the conventional concrete (1,6).

Concept of using multiple binder combinations, involving solid wastes form different sources, such as fly ash, GGBS, silica fume, etc., while still rarely used in many countries, is now an option which can be seriously considered for conventional structural concrete **(**3**).** These pozzolanic materials which serve as an excellent replacement for cement, improve the microstructural properties of concrete, making it impermeable and consequently increase the youthful age of concrete. Ternary blended cement concretes (3, 12, 13) are characterised by part replacement of cement with mineral additives and belong to that class of concretes, where the strength and durability characteristics are maximized to the highest extent possible by subtle tailoring of its chemical composition, fineness and particle size distribution.

Further, the drawback of pulverised fly ash (PFA) (3, 13) addition in terms of reduction in the rate of early strength gain and increase in the setting time can be eliminated by adding another superfine mineral admixture, Alccofine1203 is known to produce a high strength concrete and is used in two different ways as a cement replacement, in order to reduce the cement content (usually for economic reasons) and as an additive to improve concrete properties (in both fresh and hardened states). Utilization of Alccofine1203 together with fly ash provides an interesting alternative and can be termed as high strength and high performance concrete. Limited studies have been made on the PFA-Alccofine ternary blended recycled aggregate concrete and further limited data is available on the interaction of pce based polymer, a third generation superplasticizer with this concrete. The water binder ratio of PFA-Alccofine ternary blended recycled aggregate concrete can be effectively reduced by addition of a high range water reducing pce based super plasticizer (14), thus enhancing its mechanical strength performance and rendering it more durable.

The present work is an attempt to develop an equivalent ternary blended recycled aggregate concrete using pulverized fly ash and alccofine with pce based high range water reducer chemical admixture. An effort is made through this investigation to suggest a suitable quantum of replacement, expressed in terms of 'Replacement Ratio' (ratio of quantity of recycled coarse aggregates to total quantity of natural coarse aggregates), of natural coarse aggregates with recycled coarse aggregates to achieve an equivalent concrete of desired strength.

Scope of Work:

Two grades of concrete, defined by M40 and M60, are considered and an experimental investigation is conducted into the determination of replacement ratio of coarse aggregates for each of the concrete grades. Replacement ratio may be defined as the ratio of quantity of recycled coarse aggregates to the total quantity of coarse aggregates in a concrete mix. Different percentage replacements of natural coarse aggregates with recycled coarse aggregates 20, 40, 50, 60, 80 and 100 (R_r = 0.2, 0.4, 0.5, 0.6, 0.8 and 1.0 respectively) have been considered in both the grades of concrete for evaluating specimen compressive strength of the specimens.

Materials:

A. Binder Materials

Ordinary Portland Cement 53 grade (KCP Cements) confirming to IS 4031:1988, was used as the primary binding material while the supplementary cementitious materials used are fly ash (15%) and Alccofine 1203 (10%). The percentage volumes of these binder materials mentioned, are kept constant in all the mixes. Their properties are given in the Table 1 below.

Table 1: Properties of Ordinary Portland Cement 53 Grade

S.No.	PROPERTY	TEST RESULTS
1	Normal Consistency	33%
2	Specific Gravity	3.15
3	Initial Setting Time Final Setting Time	50 min 395 min
4	Fineness	6 %

Table 2: Properties of Flyash

S.No.	Major Constituents	(%)
1	SiO_2	59.03
2	Al_2O_3	25.86
3	Fe_2O_3	5.08
4	CaO	2.59
5	MgO	0.76
6	Specific Gravity	2.2

Washed natural river sand, as the finer aggregate in concrete and angular broken stone aggregates as the coarser aggregates, both confirming to IS: 383-1970 were used in concrete.

Tested laboratory specimens were crushed using the jaw crusher in the laboratory and the processed. Mechanical sieving was then done with the cylindrical sieve attached to the crusher to segregate the crushed recycled aggregates into various sizes. The crushed recycled coarse aggregates were then processed and 20mm downsizes are segregated and separated. Sieving was again done using IS sieve of size 4.75 mm to remove the finer sized particles and also the crushed mortar dust from the batch. Loose attached mortar on the recycled aggregates and mortar pieces was then removed manually. The processed recycled coarse aggregates were thoroughly pressure washed with clean water, air dried till ssd condition and then stored in bags before putting to use. The physical properties of recycled coarse aggregates are listed along with the natural aggregates in Table 3.

Table 3: Physical Properties of Aggregates

Item	Specific Gravity	Bulk density(kg/m^3)	Water absorption
Fine aggregate	2.65	1635	0.5%
Coarse aggregate, natural	2.74	1450	0.5%
Coarse aggregate, recycled	2.48	1360	3.6%

Figure 1: Recycled Aggregates Crusher and Processing Unit (Attached sieving unit)

Table 4: Different ingredients with varied proportions

S.No.	Constituents	Specifications (%)	Results (%/wt)
1	Silica (as SiO_2)	19 – 24	23.54
2	Alumina (as Al_2O_3)	3 – 6	5.03
3	Iron (as Fe_2O_3)	1 – 4	3.36
4	Calcium (as CaO)	59 – 64	60.81
5	Magnesium (as MgO)	0.5 – 4	3.20

High range water reducing pce based super plasticiser, having specific gravity 1.10, is used to reduce the water binder ratio to achieve desired strength while maintaining the concrete workable.

Methodology:

The design mix proportions for both the grades M40 and M60 will be obtained, based on the characteristic 28 days cube compressive strengths and those designed mix proportions shall then be adopted in the investigation of finding the best replacement ratio for recycled coarse aggregates in both the selected grades. Adequate number of standard specimens to test compressive strength of concrete for two concrete grades of grades M40 and M60, designed as per IS 10262-2019 and with different replacement ratios for recycled coarse aggregates, viz., 0.2, 0.4, 0.5, 0.6, 0.8, 1.0 shall be casted. The specimens will then be cured for the specified ages of curing. respectively. The tests on specimens shall be done in accordance with IS 516-1959 and the test results recorded.

Figure 2: Standard Cube specimens kept for air drying before testing

Experimental Programme:

Mix Design

The mix design for M40 and M60 grades of concrete was done based on the IS 10262-2019 guidelines and the quantities of various ingredients in concrete were calculated per cubic metre of concrete (Tables 3 & 4). The percentage fractions of flyash and alcofine were kept constant in all the mixes as 15% and 10% of cementitious material respectively. Standard size cube moulds adhering to the codal specifications, were cleaned and properly oiled oil on the inside before the freshly prepared concrete mix was poured. Proper compaction of concrete was achieved with the help of a table vibrator and the top surface of concrete in the moulds was levelled. Demoulding of the cubes was carried out after 24 hours and then the cubes were completely immersed in a clean water tank to undergo curing for the specified 7days and 28 days. After the specified curing ages, the concrete cubes were then removed from the curing tank, surface air dried and taken for testing their compressive strengths. The testing was carried out in a standard CTM apparatus, as per the guidelines in IS 516-59 and the load at failure was noted in each case. The results were tabulated and the average of 3 specimen values was calculated and reported.

A total number of 84 standard cube specimens of 150mm size were cast with varying replacement ratios for natural coarse aggregates by recycled coarse aggregates, viz., 0.2, 0.4, 0.5, 0.6, 0.8, 1.0 in each of the concrete mixes to determine the strength of ternary blended recycled aggregate concrete for curing ages of 7 days and 28 days.

Table 5: Concrete Mix Proportions for M40 Grade (in kg/m^3)

Mix type	M0	M1	M2	M3	M4	M5	M6
Rr	**0**	**0.2**	**0.4**	**0.5**	**0.6**	**0.8**	**1.0**
Cement	337.5	337.5	337.5	337.5	337.5	337.5	337.5
Flyash	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Alccofine	45	45	45	45	45	45	45
Water	131	131	131	131	131	131	131
Fine aggregate	709	709	709	709	709	709	709
Coarse aggr., natural	1200	960	720	600	480	240	-
Coarse aggr., recycled	-	240	480	600	720	960	1200
Superplasticiser	2.25	2.25	2.25	2.25	2.25	2.25	2.25

Table 6: Concrete Mix Proportions for M40 Grade (in kg/m^3)

Mix type	Mix0	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
Rr	**0**	**0.2**	**0.4**	**0.5**	**0.6**	**0.8**	**1.0**
Cement	442	442	442	442	442	442	442
Flyash	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Alccofine	59	59	59	59	59	59	59
Water	154.6	154.6	154.6	154.6	154.6	154.6	154.6
Fine aggregate	793	793	793	793	793	793	793
Coarse aggr., natural	1228.6	982.9	737.2	614.3	491.4	245.7	-
Coarse aggr., recycled	-	245.7	491.4	614.3	737.2	982.9	1228.6
Superplasticiser	4.45	4.45	4.45	4.45	4.45	4.45	4.45

Test Results

Keeping in view the impact of replacement of natural aggregates with recycled component, a comprehensive study by adopting a large range of values of replacement ratios (Rr = 0.2, 0.4, 0.5, 0.6, 0.8, 1.0), was made in order to arrive at the most optimum replacement value. For this purpose, a total of 84 nos. of standard cube specimens (150 x 150 x 150mm size) were cast, 42 nos. for each grade of concrete, to test the 7days and 28 days compressive strength. The test findings for the various replacements for both grades of concrete are tabulated and represented in the form of bar charts as below.

Table 7 : Cube compressive strengths for different curing ages

Grade of concrete	Replacement Ratio(Rr)	No of Specimens	Mean 7 Days Strength (MPa)	Mean 28 Days Strength (MPa)
M40	0	6	41.7	56.6
	0.20	6	37.5	52.4
	0.40	6	35.9	51.1
	0.50	6	34.4	50.5
	0.60	6	33.6	49.9
	0.80	6	32.8	49.1
	1.00	6	31.5	**48.5**

Table 8 : Cube compressive strengths for different curing ages

Grade of concrete	Replacement Ratio(Rr)	No of Specimens	Mean 7 Days Strength (MPa)	Mean 28 Days Strength (MPa)
M60	0	6	53.8	75.6
	0.20	6	50.3	72.8
	0.40	6	45.4	71.0
	0.50	6	44.8	**69.7**
	0.60	6	43.4	68.0
	0.80	6	39.7	62.9
	1.00	6	36.6	59.2

Figure 3: Variation of 7 Days Strength for M40 Grade

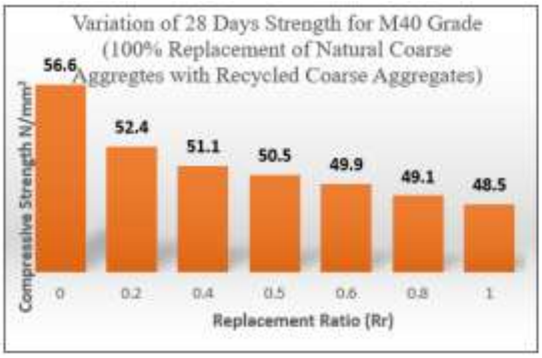

Figure 4: Variation of 28 Days Strength for M40 Grade

Figure 5: Variation of 7 Days Strength for M60 Grade

Figure 6: Variation of 28 Days Strength for M60 Grade

Results and Discussions:

Recycling and reuse provide an appropriate solution to the problem of dumping of construction and industrial wastes while effectively addressing the shortage of natural resources. The recycled coarse aggregates derived from demolished concrete wastes, and the industrial wastes such as fly ash, ggbs, etc., which serve as a supplementary cementitious material, proves to be a valuable building material in terms of technical, economic and environmental aspects. Use of recycled aggregates is recommended in spite of their higher water absorption values (4%) than the natural aggregates (0.5%) either by using them in saturated surface dry condition while preparing the mix or by making necessary corrections in the mix design to accommodate the higher water absorption value. Parametric study confirms suitable mix proportions for ternary blended recycled aggregate concrete, which attains higher early strength while reaching the desired target strength or more at the end of the 28 days curing period, for both M40 and M60 grades of concrete. Replacement of ordinary Portland cement with superfine pozzolanic materials such as fly ash (15%) and alccofine (10%) in the proposed blended concrete mixes, shall result in better packing, enhancing the strength performance of hardened concrete and may possibly render it more durable. Use of pce based super plasticiser up to 1% of cementitious material, effectively reduces the water binder ratio of the proposed concrete mixes, thus enhancing its mechanical behaviour.

1. The proposed ternary blended recycled aggregate concrete attained 130% of its target compressive strength for Rr = 0.2 and 100% for Rr = 1.0 after 28 days of curing in M40 grade and 121% for Rr = 0.2 and 116% for Rr = 0.5 after 28 day specified curing period in case of M60 grade, vis-à-vis conventional concrete (as specified in relevant BIS code).
2. The control mix (Rr = 0) yielded 141% and 126% of its 28 days characteristic compressive strength for M40 and M60 concrete grades, respectively.
3. The natural coarse aggregates may be replaced by up to 100% (Rr = 1.0) and 50% (Rr = 0.5) with recycled coarse aggregates, for M40 and M60 grades respectively, in the proposed ternary blended recycled aggregate concrete, to get an equivalent concrete exhibiting desired compressive strength.

Conclusions

The experimental investigation provides an insight into the development of a sustainable concrete, while harping on the fact that the carbon footprint can be reduced by suitably and effectively replacing cement (with fly ash and alccofine) and natural aggregates (with recycled coarse aggregates).

Based on the test results, it is observed that addition of supplementary pozzolanic admixtures viz., fly ash and alccofine with an addition of pce based chemical admixture to the recycled aggregate concrete, influences its early strength development, as all the mixes have consistently yielded excellent 7day strengths, in both grades of concrete M40 & M60.

The target compressive strength for M40 grade concrete is achieved with 100% replacement of natural coarse aggregates with recycled coarse aggregates.

The target compressive strength for M60 is achieved with 50% replacement of natural coarse aggregates with recycled coarse aggregates.

A replacement ratio, Rr = 1.0, can be recommended to get an equivalent M40 grade ternary blended concrete.

To get an equivalent M60 grade ternary blended concrete, a replacement ratio of Rr = 0.50, may be safely recommended.

The results demonstrated the potential of producing structural concrete with optimum recycled aggregate mix proportion and ternary binder system with FA as filler with OPC, and alccofine as the supplementary cementitious material.

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