Five Strategies for Recycled Aggregate Concrete

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Abstract
The construction and development work epitomizes the growth and progress of any place but at the same time, the huge quantity of construction and demolition waste around the city is a common sight. Handling these wastes is a challenge worldwide, especially for all emerging economies. On the hand, the need for developing sustainable infrastructure. The paper shares the report of the encouraging outcomes of extensive experimental research work done to produce concrete that is not just sustainable but also has vital strength and durability parameters at par with conventional concrete using recycled construction and demolition waste as a partial replacement of aggregates which workable in a fresh state and strong, and durable in a hardened state. This is achieved by applying five strategies in the study i.e., using pre-wetted recycled aggregates as an internal curing agent, intentionally using extra class f fly ash in the mix, the optimized fragmented gradation of aggregates (both fine as well as coarse) for minimizing voids and maximizing density, and, the addition of glass fiber (nominal dose). Understanding the behavior of different particle sizes of the aggregates, as a function of workability, using an optimized fragmented gradation of aggregates, helps to achieve a concrete mix which as per IS 456:2000 can be classified as medium workable is achieved for a constant water-cement ratio and superplasticizer dose. The presence of proper grain sizes in the mix referred to as optimized gradation in the paper has a positive effect on various essential performance parameters of the concrete not just in the fresh state but also in the hardened state and offers a higher probability of service life. The dual use of additional class f fly ash an abundantly locally available industrial byproduct along with a simultaneous nominal dose of glass fiber in the mix has multifold benefits on the hardened properties of this internally cured concrete. Internal curing of concrete reduces the early-age shrinkage and also delays the rate of diffusion of water in the mix helping to achieve a higher degree of hydration and pore refinement of the mix. The fractions of additional fly ash which remain unhydrated in the concrete mix will act as a micro filler resulting in a well-packed concrete mix, lowering bleeding, and porosity possibilities which is a prerequisite for strong and robust concrete having a high probability of service life and no durability issues. The strategies presented are also viable from a field application point of view and are likely to attract the attention of the construction industry and concrete researchers for wide applications.
Keywords— Internal curing, recycled aggregate, optimized gradation, additional fly ash.

1. Introduction

It is the duty of the concrete fraternity to produce concrete that is not just strong and durable but sustainable as well by adopting innovative solid waste utilization and recycling techniques. Researchers across the world demonstrated the possibility of using Construction and Demolition (C&D) waste as a sustainable substitute for natural materials as a partial solution to the challenges of Sustainable Infrastructure Development. The history of recycling demolition waste dates to the post-Second World War when countries had twin problems of disposing of the sizable amounts of demolition waste due to the war and producing raw materials for new construction. Today emerging economies like India find themselves in a similar fix as India is being reconstructed which means a lot of existing structures will be demolished and massive construction activities will go on simultaneously. Illegal dumping, along with unplanned disposal of these C&D waste in and around the city limits is adding to the complexity of solid waste management which is also affecting ecology and the environment.[1] Plenty of literature is available on the intentional use of recycled aggregates (RA) as a partial replacement of natural aggregates for producing concrete is available but as far as a full-fledged application in practice is still far away from reality because of various technical and non-technical factors like non-availability of infrastructure and resources for recycling aggregates, lack of awareness amongst construction fraternity about the possibilities of use of RA, non-availability of recycled products and low returns from investment in recycling units [2].

On the material scale, the performance of concrete produced using RA derived from the C&D waste is still under scanner for their workability and durability issues. The rough texture of RA due to a preexisting coating of mortar increases surface water demand and yields a harsh mix that is difficult to compact; the concrete thus produced is with prominent ITZ which is the root cause of its performance issues. The present research is a humble attempt to produce sustainable concrete using RA for partially replacing coarse and fine aggregates and the concrete thus produced is not just strong and durable but also workable. For the stakeholders from the school of thought who believe that sustainability is priceless, the proposed concrete is economical as well.

The various current research issues in the field of concrete technology can be referred to in Table 1.1 [2] to address these issues in the study various state-of-the-art technologies in concrete are integrated and strategically applied in the present study. [3] Wide research on internal curing (IC), using superabsorbent polymer (SAP) and available pre-wetted lightweight aggregate(LWA) has been carried out and reported. The IC agent acts as a tiny water reservoir within and across the hydrating concrete mix which undergoes self-desiccation during hydration which leads to differential humidity levels between the fully saturated IC agent and hydrating paste. [4] Using fine aggregate as an IC agent is advantageous over coarse aggregate as their distribution in the mix is wider and more uniform. [4] Moreover, it offers a larger contact surface area with the thirsty hydrating cement paste around it and is desired for IC efficacy. IC is also vital for the Indian construction industry where early-age curing is often neglected due to negligence and site constraints. However, using RA as an IC agent specifically in the subtropical region not much work is in the knowledge domain where concrete is more susceptible to curing. To bridge this gap, an experimental study is carried out in the hot and dry summer season with an ambient casting time temperature of $30^0 \pm 2^0$C and relative humidity of 56 ± 4 percent. From the existing wisdom, concrete produced by using RA as a replacement to natural aggregates leads to a considerable drop in vital concrete properties like strength, workability, and durability. To compensate for these losses:

i. Predetermined sizes of both coarse and fine fractions of RA are pre-wetted and used as an IC agent.
ii. Dual application of locally available industrial by-product fly ash (class F), to apparently lower the water-cement ratio (w/c ratio) and as fillers or micro-aggregates.
iii. Aggregates form the bulk in concrete and are responsible for all the essential properties of concrete in the fresh and hardened state. Optimized gradation of coarse as well as fine aggregates helps in improving the workability and packing of the concrete matrix.
iv. Reducing the w/c ratio restrains bleeding and shrinkage and the use of additional flyash also increases the paste in the mix which enhances rheology.
v. Lastly, already-proven high-performance glass fiber is also used in nominal doses to make up for the loss in the strength and durability of concrete.

Already the shortage of natural resources like sand for producing concrete is reported from various cities and desired quality of sand in the required quantity is also not available. It is high time to explore the alternatives without compromising the vital properties of concrete. The parametric study of concrete produced, using 0.4 w/c ratio is done: In Phase, I three replacement dosages of RA are considered. In Phase II concrete with RA and two dosages of additional fly ash is investigated and in Phase III concretes a single nominal dose of glass fiber used in the above mix is examined. The study is to rediscover the potential use of the discarded material as a natural sand replacement like the use of crushed bricks (CB) which is a C&D waste and can be used as an internal curing agent. As it shows a promising future for wide applications for sustainable, clean and green environment. Representative results from the study are presented.

Table 1: Contemporary issues in Concrete [2]

To lessen the unhydrated cement fractions in the hardened concrete.
To address vulnerability issues of Interface Transition Zone (ITZ).
To enhance the effectiveness of external curing.
To reduce the use of depleting natural resources. (sand)
To restrain early age shrinkage.
To exploit the C and D waste as resources in construction.
To lessen the water footprint in concrete production.

2. Materials and Methods

A. Material Specification

ASTM C150 type I Ordinary Portland cement (OPC- 43 grade) with chemical composition in compliance with IS3812:1987 is used properties are tabulate in table 2 and table 3.

Table 2: Cement Chemical Composition

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	Ignition loss	Ash	Tot. Content (wt %)
20.92	3.50	4.38	64.69	1.20	3.07	0.22	0.38	0.082	1.27	0.26	99.97

Table 3: Technical parameters of cement

Sieve fineness	Consistency (%)	Initial setting time (min)	Final setting time (min)	Soundness Le Chatelier (mm)	Compressive strength 28d (MPa)	Specific Gravity
3.2%	33	77	186	2	45.6	3.1

Conplast SP430 sulfonated naphthalene super plasticizing admixture is used at a fixed dosage of 1% (1g per 100g of cement) based on the desired workability at the worst site condition in sub-tropical climate with glass fiber. The natural river sand confirming Zone-II as per codal provisions of IS 383-2013 having an apparent specific gravity of 2.62 is used. Coarse aggregate of 20 mm and 10mm down size are procured. Properties are listed in Table 4.

The class F fly ash is procured from local power plant NTPC, Bhilai. Locally available bricks were crushed and sieved into desired sizes (1.18mm- 2.36mm). Owens Corning Cem-Fil Anti Crak HD make Glass Fiber procured from local vendor is used, which causes lumping in the mix and also affects the workability and compaction. The fiber dose used is 0.2% as per the datasheet of the supplier.

Table 4: Properties of Aggregates used in the study

Properties	Coarse Aggregate			Fine Aggregate
	Normal Aggregate (NA)		Recycled Aggregate (RA)	
	20mm to 10 mm	10 mm to 4.75 mm	20mm to 10 mm	
Water absorption (%)	0.50	0.58	4.62	1.00
Specific Gravity	2.72	2.70	2.63	2.62
Bulk density (Loose) kg/litre	1.39	1.29	x	1.61
Bulk density (Rodded) kg/litre	1.53	1.51	x	1.75
Bulk density (Vibrated) kg/litre	1.63	1.64	x	1.84
Percentage void (Loose)	48.00	51	x	38.50
Percentage void (Rodded)	43.5	44	x	33.13
Percentage void (Vibrated)	39.9	40	x	29.77
Crushing Value % (IS 2386 part IV)	13.85		29.9	x
Impact Value (in %)	8.86		27.6	x

Sulfonated naphthalene polymers based super plasticizing admixture (Conplast SP430) used. Dose is fixed as 0.6% (0.6g per 100g of cement) across the study for a desired workable mix for all the replacements levels of coarse and fine aggregates with recycled aggregates. As fine aggregate zone-II as per IS 383-2013 natural river sand having 2.62 as its apparent specific gravity. 20mm down size crushed aggregate is used. The Fly ash confirming to IS: 3812 (Part-1) used. Distilled water is processed in lab and is used as mixing water.

B. Preparation of materials

A parametric study using proportions given in Table 7 with 0.4 w/c ratio with constant cement content and the chemical admixture is carried out with three replacements of natural coarse aggregate with RA and sand with CB. *Strategy one* is the preparation of coarse aggregate for which 20 cubic feet of 20mm size coarse aggregate is procured and sieved into three size fractions: 4.75-10mm, 10-16mm and 16-20mm fraction greater than 20mm size is discarded. Using this fragmented coarse aggregate a series of workability tests is carried out using various combinations of percentage and size fraction replacements of coarse aggregate with RA. To achieve the desired range of workability without changing the w/c ratio and admixture dose; RA of 10-20mm size is bottlenecked as a suitable replacement for natural coarse aggregate as this size fraction has lesser surface water demand compared to lower sizes. Round natural aggregates are intentionally used in the size range 12.5 mm to 4.75 mm and eliminating all elongated and flaky aggregate also helped in improving workability considerably. *Strategy 2* is to optimize the proportioning of coarse aggregates to achieve maximum density using various combinations of percentages of each size fraction. Eventually, the percentages of various fractions of coarse aggregates i.e. 16-20mm, 10-16mm and 4.75-10mm used in the mix are 38%, 32% and 30%. With 65% replacement in 16-20mm size fraction and 35% replacement in 10-16mm size fraction worked well from a workability standpoint also. It is worth mentioning here that when coarse aggregate is replaced with RA with lower specific gravity larger volume of RA comes into the mix as a replacement. The properties of aggregates (both coarse and fine) are in Table 4.

Understandably, RA with an average water absorption capacity of 4.62% is not an effective IC agent. Another constituent of C&D waste, crushed bricks (CB) with water absorption greater than 10% is used to impart the positives of IC to the concrete. Using a 2.36-4.75 mm size fraction of CB as an IC agent is *strategy three* in the study which is used as a partial replacement to natural sand confirming to zone II. In the study two IC agents with varied water absorption and desorption capabilities are used simultaneously; in such a situation quantity of water in the mix should be critically evaluated. The average water absorptions of RA and CB are ascertained. The RA and CB as per the mix design are submerged in a known quantity of water for 24 hours in a closed container ensuring no loss of water due to evaporation. The total water used in the mix is equal to water as per the mix design plus the absorption capacity of RA and CB. For mixing, the coarse aggregates, sand, cement, and fly ash as per mix proportions are allowed to homogenize, and subsequently, the presoaked RA and CB with the required final count of water and admixture are added. This will ensure a consistent quantity of water in the subsequent mixes. The mixing process is more or less the same but a word of caution for RA and CB is that they should not be mixed with dry coarse aggregates and sand. [2]

For a constant dose of chemical admixture and cement, to improve the rheology of the mix to enhance compaction without segregation increase in paste content is required. *Strategy five*, in the study, is to use another abundantly available industrial byproduct class-f fly ash in two size fractions: 90 microns passing and 90–150-micron fly ash used as micro aggregates. The use of additional fly ash imparts multifold benefits to the concrete mix, it is the cheapest source to increase paste content, prevents bleeding, and shrinkage, imparts later age strength, and better particle packing of the mix, and will yield durable concrete. Calculation of the requirement of class F fly ash which is passing through 90 microns sieve is given in Table 5. By apparently lowering the w/c ratio of the mix by adding the required quantity of fly ash only and no cement is added. For calculation w/c ratio is reduced from 0.4 to 0.38 and then to 0.36, Quantity of additional 90–150-micron fly ash to be used in the mix is calculated by minimizing voids. [2]

B.1. Quantity of additional fly ash used

Additional class F fly ash to be used in the concrete mix is quantified by lowering the w/c ratio from 0.4 to 0.38 and then to 0.36. Additional 90-micron sieve passing fly ash is used without any addition of cement the calculation is shown in table 5.

B.2. Quantity/ Mass of Internal curing agent (MRA) for intended level of Internal Curing

To calculate the dry mass of IC agents required in the mix Bentz & Snyder [5] equation is used. The equation is formed by equating demand of water to the potential supply of water by IC agent. The calculation of the demand of IC water required for desired hydration and the dry mass of IC agent based on its desorption capacity to supply the same. Calculation is shown in table 5.

$$MRA = \frac{Cf\ x\ CS\ x\ \alpha max}{Sx\ \phi RA} \quad (1)$$

Where:

Cf = cement content in concrete (kg/m3);

α_{max}= maximum expected degree of hydration of cement;

CS= chemical shrinkage of cement (g of water/g of cement) = 0.7 [3];

φ_{ICA} = absorption of IC agent = 10.2% used is the desorption capacity of the crushed bricks at 92% RH.

S = degree of saturation of aggregate (0 to 1);

Table 5: Quantity of additional Fly Ash (Class F) used for apparently reducing w/c ratio in the mix.

From Mix Design			{(Quantity of water in mix) / (Target w/c ratio - Cement Content)} *100 / Cement content	Target w/c ratio	
W/C ratio	Cement Content Kg/m^3	Water		0.36	0.38
				Fly ash % required	
0.4	400	160		11.11	5.26

Table 6: Calculation of MRA & CB Required

Mass of dry Recycled Aggregates (MRA) & Crushed Bricks (CB)

Degree of	φ_{RA}, Avg. water absorption of	φ_{RA}, Avg. water Absorption of

Hydration	RA = 4.6%,		CB = 12.24%,	
	As per mix design the Qty of natural aggregates (NA) in the mix= 1197 kg/m^3		As per mix design the Qty of natural sand in the mix= 667 kg/m^3	
	w/c ratio= 0.4, Cement Content (Cf) = 400kg/m^3 CS = 0.7			
α_{max}	$M_{LWA,}$ Required Mass of IC agent (dry RA) kg/m^3	Replacement of NA (%age)	$M_{LWA,}$ Required Mass of IC agent (dry CB) kg/m^3	Replacement of Sand (%age)
0.2	121.739	10.17	51.48	8.4
0.3	-	-	77.22	12.59
0.4	243.478	20.34	103.02	16.79
0.5	304.348	25.43	128.7	20.99
0.6	365.217	30.52	154.44	25.19
0.8	486.957	40.69	205.92	33.59
1	608.696	50.86	257.39	41.99

Ingredients for producing concrete are stored at room temperature. 256 cubes, 100x100x100mm size are casted, cured and tested for determining 7d, 28d and 56d (days) compressive strength. 96 beams of size 500x100x100mm are cast, cured, and tested for 28, 56 days flexural strength. The test specimen is demoulded, and then cured after 24 h from the time of casting. Proper curing is ensured to achieve favorable end results as additional fly ash is used in the mix.

C. Experimental Studies

C.1. Fresh concrete properties

Slump Cone, Compaction Factor, Schleibinger Rheometer EBT-2, for Shrinkage Schleibinger Shrinkage Cone is used (deltaEL), Electrical resistivity Two-probe (electrode) Method (Giatec RCON2™) is adopted to measure the Bulk Resistivity in concrete samples.

C.2. Compressive Strength

American Society for Testing Materials C39 / C39M (ASTM) is referred for determining the 7d, 28d and 56d compressive strength using concrete cubes specimen 100 mm× 100 mm ×100 mm size, the rate of loading applied = 140 kg/cm^2 per min.

C.3. Flexural Strength

ASTM C78 / C78M – 16 is referred for determining the 28d flexural strength on specimens 100 mm×100 mm×500 mm size simply supported and third-point loading, spacing between supports = 400 mm.

C.4 Electrical Resistivity

Bulk Electrical Resistivity Test (ER) is carried as per the guidelines of ASTM C 1202. The surface dry and fully saturated specimen cubes are covered with moist sponge of ER meter and placed between the probes which are two parallel metal plates.

Small alternating current (ac) is applied at intended frequency to measure the voltage between two ends of the specimen. The measured impedance, Z can be recorded from the monitor of ER meter. Concrete resistivity is determined using eqn (2):

$$\rho = \frac{\text{A x Z}}{L} \qquad (2)$$

Where:

ρ denotes the resistivity of specimen (cube) (Ωcm),

L(cm) are the cross-sectional area and length of specimen.

A (cm^2), Z denotes impedance measured by device (Ω).

C.5. Microstructure Investigations

Zeiss Scanning Electron Microscope (SEM) machine is used that is enabled with a system for chemical compound analysis based on Energy Dispersive Spectrometry. Specimen size is 4-5 mm which is extracted from the concrete cubes fractured during the compressive strength test. This 4-5 mm specimen surface is polished. Then it is mounted for gold coating on a gold sputter coater. Then finally for scanning the image specimen is mounted on an aluminum stub at high resolution. [18] A few SEM images are presented in Figure 6 taken at various magnifications of different mixes as per our study requirement.

C.6. Carbonation

Carbonation test is an indication of the durability of concrete and also service life of reinforced concrete. [1, 2, 10, 14] Three cube specimen of each mix (1-16) is casted and cured for 56 days. The air-dried samples are placed in the carbonation chamber care should be taken while placing the specimen so that the air circulation in the chamber is not restricted. The chamber setting temperature of 33^0C is kept constant and the chamber humidity is 70%, carbonation rate used is 5%. The reason for setting high chamber temperatures is to simulate a warm sub-tropical climate. Accelerated carbonation for 60 days is carried out in the chamber. The cubes are fractured in CTM and using a brush their inner surface is cleaned to remove any dust or loose particles. Then, the phenolphthalein test is adopted to measure carbonation depth in the specimen it is a colorless acid indicator that will turn pink when the specimen is alkaline. Its solution is sprayed on the fractured specimen surface. When the pH of the specimen is more than 9.5 color changes to bright pink. Carbonation depth is measured from the surface and the depth of the specimen in which no color change is observed is an indication of carbonation in the specimen. [14]

Table 7: Summary of mix design

Cement= 400kg/m^3, Water= 160kg/m^3, Admixture 2.4kg/m^3				
Coarse Aggregate =1197kg/m^3, 16-20mm = 38% (65% replacement) | 10-16mm =32% |4.75-10mm = 30%. Sand = 667kg/m^3				
MIX	Recycled Aggregate	Crushed Bricks	Additional Fly ash	Glass fiber
	% Used	% Used	% Used	% Used
MIX-1	0	0	0	0
MIX-2	40.69	12.59	0	0
MIX-3	30.52	16.79	0	0
MIX-4	20.34	20.99	0	0
Additional Fly Ash 5.26% = 21.04 kg/m^3				

MIX-5	40.69	12.59	5.26	0
MIX-6	30.52	16.79	5.26	0
MIX-7	20.34	20.99	5.26	0
Additional Fly Ash 11.11% = 44.44 kg/m^3				
MIX-8	40.69	12.59	11.11	0
MIX-9	30.52	16.79	11.11	0
MIX-10	20.34	20.99	11.11	0
Additional Fly Ash 5.26%= 21.04 kg/m^3 + 0.2 % GF				
MIX-11	40.69	12.59	5.26	0.2
MIX-12	30.52	16.79	5.26	0.2
MIX-13	20.34	20.99	5.26	0.2
Additional Fly Ash 11.11%= 44.44 kg/m^3 + 0.2 % GF				
MIX-14	40.69	12.59	11.11	0.2
MIX-15	30.52	16.79	11.11	0.2
MIX-16	20.34	20.99	11.11	0.2

C.7. Degree of hydration

The specimen is prepared from a fractured cube (56 days) using a compression testing machine and then it is further ground so that the specimen is fine enough to pass a 150-micron sieve the idea is to determine the non-evaporable water in the specimen which is a measure of the degree of hydration (DoH), as suggested by L. Lam et. al. [19]. Step one is to measure the loss on ignition (LOI), then Wn and degree of hydration are calculated.

To determine LOI, Equation (3) is used to calculate the hydrated cement pastes:

$$\text{LOI (\%)} = \frac{\text{(weight of sample – ignited weight)}}{\text{ignited weight}} \qquad (3)$$

Wn is determined by oven drying a 150-micron sieve passing 5 g of a grounded hydrated sample at a temperature of 110°C for a duration of 3 hours and then igniting at a high temperature of 950°C for a time duration of 1 hour in an electric furnace.

The Wn is calculated by using equation (4):

Wn (%) = 100 x [(weight of dry sample – ignited weight of sample)/ (ignited weight of sample) – LOI] (4)

Wn = 0.23g for hydration of 1 g of anhydrous cement [2].

The DoH (%) of the cement = 100 x (Wn) / 0.23 (5)

3. Results and Discussion

The prime objective of the study is to improve the workability, strength, and durability of the concrete made using C&D waste as partial replacements of natural aggregates both fine as well as coarse. The experimental observations of the parameter tested are presented in reference to the control mix in Table 8-9, and durability indices observations are tabulated in Table 10. To summarize the intention, methodology, and findings of the study the section is further divided into three sections properties of fresh concrete, the strength of hardened concrete, and other durability indices.

A. Study on fresh concrete properties

The mix which involves partial replacements of natural aggregates with the rough textured presoaked RA and CB with poor geometry affects workability considerably. Adopting various strategies as discussed earlier in section II all the mixes with various replacement percentages of aggregates along with additional fly ash and glass fibre falls in as a mix with medium degree of workability as per IS 456: 2000 classification which is suitable for most of the normal RCC and concrete work. The test results help to understand the effect of optimized gradation of coarse aggregates and fixing the percentage of size fractions of coarse aggregates (20-16mm, 16-10mm and 10-4.75mm) in the mix facilitate to enhance workability. Further replacing only larger size fractions of NA with RA also contributes to the cause. Use of additional fly ash in its natural state (i.e not grinded) has spherical shape, glassy texture and deflocculates cement particle thus also enhances workability. [9, 10] The advantage of using additional fly ash on the properties of fresh concrete is not just limited to this only; the rheology of the mix also improves which is not obvious in slump cone or compaction factor test result, additional fly ash increases the paste content in the mix which reduces the shear stress in the fresh mix which facilitates in mixing and compaction of concrete. Further, use of additional fly ash prevents bleeding, reduces plastic shrinkage and improves packing. This is manifested by a considerable reduction in shrinkage and an increase in electrical resistivity. Internal curing mechanism with pre-soaked crushed bricks (CB) also restrain shrinkage and delay the rate of diffusion of water in the mix which is validated by the electrical resistivity result showing availability of pore water for a longer time compared to the control mix. Addition of glass fibre in the mix reduces workability in general but it imparts tensile strength to the fresh concrete leading to the bundling of the mix which in turn contributes to further reduction in the shrinkage of fresh concrete.

Table 8: Percentage Variation in fresh concrete properties with reference to control concrete

Mix	Description	Slump	CF	Yield stress	Shrinkage	Electrical resistivity
1	0 % FA + 0 %RA+0 %CB +0 %GF	0	0	0	0	0
2	0 % FA + 40.69 %RA +12.59 %CB+0 %GF	-13.6	-1.9	+18.7	-17.6	- 8.3
3	0 % FA + 30.52 %RA +16.79 %CB+0 %GF	-18.2	-3.5	+38.8	-22.2	-10.7
4	0 % FA+20.34 %RA +20.99 %CB+0 %GF	-18.2	-3.8	+48.1	-25.4	-13.4
5	5.26%FA + 40.69%RA +12.59 %CB+0 %GF	0	-0.9	- 4.5	-24.9	- 1.1
6	5.26%FA + 30.52%RA +16.79 %CB+0 %GF	- 4.5	-1.8	- 2.2	-26.3	- 4.9
7	5.26%FA + 20.34%RA +20.99 %CB+0 %GF	- 9.1	-2.9	+0.7	-29.5	- 8.9
8	11.11%FA+40.69%RA +12.59 %CB+0 %GF	-9.1	-1.4	+ 6.6	-30.3	+ 3.8
9	11.11%FA+30.52%RA +16.79 %CB+0%GF	-13.6	-3.7	+12.6	-34.9	+ 0.2
10	11.11%FA+20.34%RA +20.99 %CB+0 %GF	-13.6	-5.0	+18.9	-37.3	-2.7
11	5.26%FA + 40.69%RA +12.59 %CB+0.2%GF	-18.2	-4.5	+33.5	-34.5	+4.2
12	5.26%FA+30.52 %RA +16.79 %CB+0.2%GF	-18.2	-5.7	+38.3	-38.8	-0.2
13	5.26%FA + 20.34%RA +20.99 %CB+0.2%GF	-22.7	-6.7	+46.9	-41.8	-1.8

14	11.11%FA+ 40.69% RA+12.59 %CB +0.2%GF	-22.7	-6.4	+46.9	-41.2	+5.83
15	11.11% FA+ 30.52%RA +16.79%CB +0.2%GF	-27.3	-7.8	+5.2	-42.6	+3.8
16	11.11% FA+ 20.34%RA +20.99%CB +0.2%GF	-31.8	-9.3	+9.1	-44.3	+3.4

B. Properties of hardened Concrete

The properties of hardened concrete are a function of various factors. Using C&D waste as a replacement for natural aggregates in concrete has an instantaneous detrimental effect on its compressive and flexure strength. The prominent loss seen in the early age strength of concrete is especially due to the use of CB. The paste around this CB particle itself doesn't have enough strength to shield the marginal material and failure under load is seen through the CB particle, with age the surrounding paste gain strength and shields the marginal material. Thus, with age, the gap between the percentage loss in compressive strength due to the use of the marginal material decreases. The increase in the later age strength is the cumulative effect of pozzolanic reaction, restrained shrinkage, and control bleeding by the use of fly ash and internal curing action. In the study, using strategies resulted in a medium workable mix that can be compacted easily with lesser effort and energy a well-compacted concrete with better strength properties is obtained.

Table 9: Percentage Variation in Strength with reference to control concrete

	Compressive			**Flexure**	
	7 days	**28 days**	**56 days**	**28 days**	**56 days**
Level 1 replacement 40.69% RA + 12.59% CB					
40.69% RA + 12.59% CB	-6.26	-4.38	-4.26	-10.4	-8.17
40.69% RA + 12.59%CB +5.26% FA	4.96	5.48	4.96	-3.92	-1.97
40.69% RA + 12.59%CB +11.11% FA	6.3	6.59	5.66	4.11	6.12
40.69% RA + 12.59%CB +5.26% FA+0.2%GF	11.42	10.95	10.64	12.24	12.94
40.69% RA + 12.59%CB +11.11% FA+0.2%GF	12.83	13.14	10.91	18.76	19.4
Level 2 replacement 30.52% RA + 16.79% CB					
30.52% RA+ 16.79% CB	-9.45	-9.05	-8.81	-18.4	-15.5
30.52% RA+16.79%CB +5.26% FA	2.8	4.38	2.47	-8.54	-6.19
30.52% RA+16.79%CB +11.11% FA	3.66	4.84	2.83	-2.3	-1.31
30.52% RA+16.79%CB+ 5.26% FA+0.2%GF	7.6	9.51	8.85	6.39	5.89
30.52% RA+16.79%CB+ 11.11% FA+0.2%GF	10.87	11.39	9.15	8.81	9.87
Level 3 replacement 20.34% RA + 20.99% CB					
20.34% RA+20.99% CB	-16.0	-9.48	-10.3	-22.4	-20.6
20.34% RA+20.99%CB +5.26% FA	-2.13	2.78	0.7	-10.6	-12.5
20.34% RA+20.99%CB+ 11.11% FA	-0.94	3.15	1.34	-8.54	-6.19
20.34% RA+20.99%CB+ 5.26%	1.81	6.57	4.53	5.78	5.81

FA+0.2%GF							
20.34% FA+0.2%GF	RA+20.99%CB+	11.11%	3.54	9.2	6.66	8.36	8.76

The fracture of the concrete specimen having additional fly ash shows a dense and compact fracture. The use of additional fly ash offers a higher surface area to bond well with the cementitious material apart from contributing as a Pozzolan or else as a micro filler. The 7 days compressive strength of concrete with additional fly ash with increasing percentage replacement of natural aggregates with recycled aggregates (RA) is lower in most cases compared to the control mix. The 28-day compressive strength of all the mixes with RA and additional fly ash is observed to be greater than the control mix. The use of additional flyash in two sizes 90-micron passing and 150-90 micron fly ash essentially improves the packing of the matrix which is validated by Scanning electron microscope (SEM) images (figure 1 and 2) and electrical resistivity test. The use of additional fly ash could not improve the flexural strength of the composite as per expectation. To ensure strong and durable concrete using a marginal material a nominal dose of glass fibre is used resulting in an increase in the compressive and flexural strength of concrete. The use of fine fly ash with glass fibre reinforced internally cured concrete improves the fibre bond which is strongly desirable for the long-term serviceability of concrete. The intended advantage of using a nominal dose of glass fibre in the mix is observed in the flexural strength test results of the concrete. The Increase in flexure strength with age is also attributed to internal and external curing due to a higher degree of hydration (DoH).

C. Durability Indices of Concrete

IC of concrete using an under-rated IC agent CB is validated by Shrinkage, electrical resistivity (ER), DoH test results, and SEM images. Additional fly ash in the mix reduces its pore size thus the capillary pull which is inversely proportional to the pore size of the desiccating paste is increased. Due to this pore refinement, the efficacy of the IC of CB is increased which has relatively smaller pores compared to other contemporary IC agents used in the research. The combined action of additional fly ash and IC mechanism in concrete restrained the early-age plastic shrinkage and delayed the rate of diffusion of water in the mix which resulted in higher DoH and imparted better microstructure and low permeable concrete. Better hydrated products and higher DoH in concrete are desirable from a durability standpoint. Glass fiber in the mix imparts tensile strength to the fresh concrete which restrains bleeding and shrinkage thereby imparting a dense and compact micro-structure essential for durability which is manifested by a trend of increase in ER readings.

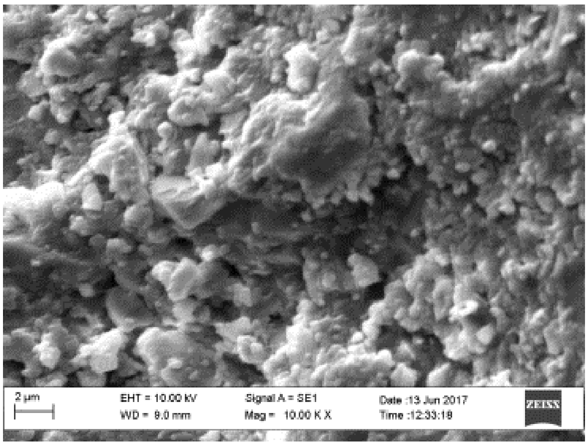

Fig.1: SEM images of 28days cured concrete with crushed bricks as an internal curing agent and an additional dose of fly ash (0.4 w/c ratio)

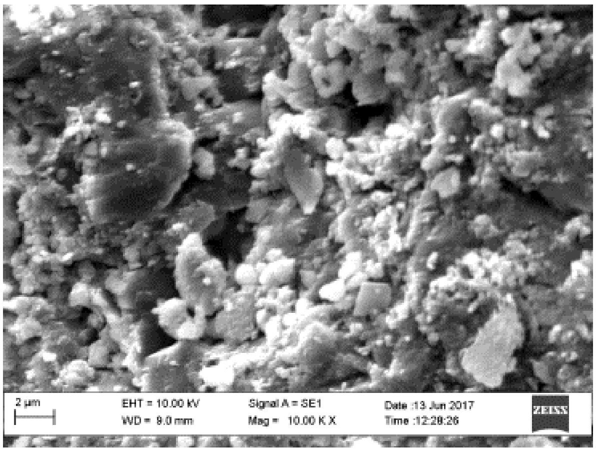

Fig.2: SEM images of 28days cured control concrete and concrete with crushed bricks as an internal curing agent and an additional dose of fly ash (0.4 w/c ratio).

Table 10: Durability Index Test on Concrete w/c ratio 0.4

	Carbon-ation Depth	Electrical Resistivity		DoH (28d)
	mm	Z (Ω)	Ψ	%
CNTL MIX	5	942	0	50.3
40.69% RA +12.59% CB	5	964	0	56.7
40.69% RA + 12.59%CB + 5.26% FA	4	998	1	59.4
40.69% RA + 12.59%CB + 11.11% FA	3.5	992	1	61.5
40.69% RA + 12.59%CB + 5.26% FA+0.2%GF	3	1018	1	61.4
40.69% RA + 12.59%CB + 11.11% FA+0.2%GF	3	1028	1	61.8
Level 2 replacement 30.52% RA + 16.79% CB				
30.52% RA+ 16.79% CB	5.5	928	1	58.4
30.52% RA+16.79%CB+ 5.26% FA	4.5	971	0	60.1
30.52% RA+16.79%CB+ 11.11% FA	4	967	1	62.2
30.52% RA+16.79%CB+ 5.26% FA+0.2%GF	3	978	1	61.8
30.52% RA+16.79% CB +11.11% FA+ 0.2%GF	3	989	1	63.5

Level 3 replacement 20.34% RA + 20.99% CB				
20.34% RA+20.99% CB	6.5	891	1	60.1
20.34% RA+20.99%CB+ 5.26% FA	5	953	0	60.8
20.34% RA+20.99%CB+ 11.11% FA	4	954	0	62.6
20.34% RA+20.99%CB+ 5.26% FA+0.2%GF	3.5	947	0	62.5
20.34% RA+20.99%CB+ 11.11% FA+0.2%GF	3.5	962	1	64.1

Some of the observations are against the existing literature on concrete which need to be verified. The use of fly ash in concrete proposes an increase in the carbonation depth but the use of additional fly ash in combination with internal curing of the concrete shows a different result in the study. A decrease in carbonation depth is observed is may be due to the lowering of the effective w/c ratio with an increasing percentage of fly ash in the matrix. Further, higher doh should result in higher chemical shrinkage, but in the present study, the use of multiple strategies successfully restrained shrinkage in spite of an increase in doh.

4. Conclusion

The multiple strategies discussed in the paper have to offer a lot to the industry obsessed with workability, strength, durability, and microstructure of the concrete keeping use of recycled aggregate away from the site implementation. The study offers sustainable concrete using construction industrial byproduct recycled aggregates for field and practical implementations having properties at par with conventional concrete. The use of class f fly ash which is locally available in abundance is a sustainable and cheap admixture to reduce shrinkage and bleeding is also recommended for increasing the carbonation resistance of the concrete thus producing a higher degree of hydration due to IC. The unhydrated fraction of fly ash is influential in offering a dense, well-packed particle matrix having low porosity which is requisite for durable concrete having a higher probability of service life. Simultaneous application of a nominal dose of glass fiber and additional fly ash imparts multifold benefits to the internally cured concrete using a marginal material calls for a wider application. The noticeable improvement in the strength, durability, and microstructure of concrete in the present study is also due to the combined action of both internal and external curing without any appreciation in the cost but has the potential to save curing water and natural aggregates for a given strength, which is also a sustainable outcome for a clean society and green environment.

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