Strategies to produce Strong, Workable and Durable Concrete using Recycled Aggregates

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Abstract
The enormous construction and development epitomize progress and growth but the mammoth quantity of construction and Demolition Waste (C and D Waste) is the other side of the same coin. All the emerging economies of the world are facing the challenge of handling the C and D waste are driven by the imperative for sustainable infrastructure development. The paper reports the encouraging results of the extensive experimental study in quest to produce a strong, workable, durable and sustainable concrete by using recycled C and D waste as a partial replacement of both coarse and fine aggregates. The paper revolves around the intentional use of five strategies including the use of recycled aggregates as internal curing agents, use of additional fly ash, optimized gradation of both coarse and fine aggregates and finally, the use of a nominal dose of glass fibre will leave no scope for any suspicion for strength and durability. With better understanding of the function of various particle fractions of the aggregates, a medium workable concrete mix as per IS 456:2000 can be ensured using recycled aggregates for a given water-cement ratio and superplasticizer dose. The optimized gradation also has a good affect on all the performance indices of the concrete - workability, strength, and durability. The simultaneous use of additional fly ash and glass fiber impart multifold benefits to the internally cured concrete, the early age plastic shrinkage is restrained and the rate of diffusion of water in the mix is delayed results in higher degree of hydration which also leads to pore refinement. The unhydrated fraction of an abundantly available industrial byproduct fly ash in concrete acts as a micro filler material helps to resist bleeding, offers a well-packed matrix with lower porosity which is essential for durable concrete with higher predictability of service life at a nominal cost. The simplicity of the strategies will attract the industry and researcher for wider applications in future.
Keywords— Internal curing, recycled aggregate, optimized gradation, additional fly ash.

1. Introduction

It is the duty of concrete fraternity to produce concrete which is not just strong and durable but sustainable as well by adopting innovative solid waste utilization and recycling techniques. The 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 of demolition waste dates to the post Second World War when countries had twin problems of disposing the sizable amounts of demolition waste due to the war and to produce raw materials for new construction. Today emerging economies like India finds itself 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. Issues like illegal dumping and unplanned disposal of the C&D waste within the city limits is adding to the complexity of the solid waste management which is also affecting ecology and environment.[1] Plenty of literatures on the use of recycled aggregates (RA) as replacement to natural aggregates in concrete is available but their full-fledged use in practice is far from reality due to various factors like lack of awareness of the possibilities of recycling, non-availability of recycled products and low returns from investment in recycling units [2].

On 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 preexisting coating of mortar increases surface water demand and yields a harsh mix which 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 a workable, strong, durable and sustainable concrete, using RA as partial replacement of both fine and coarse aggregates. For the stakeholders from the school of thought who believe that sustainability is priceless, the proposed concrete is economical as well.

To address to the various contemporary issues of concrete listed in table 1.1 [2].various state-of-the-art technologies in concrete is integrated and strategically applied in the present study. [3] Wide research on internal curing (IC), using various pre-wetted lightweight aggregate and superabsorbent polymer has been carried out and reported. The IC agent acts as tiny water reservoir within and across the hydrating concrete mix which undergoes self-desiccation during hydration which leads to differential humidity levels between fully saturated IC agent and hydrating paste. [4] Using fine aggregate as an IC agent is advantageous over coarse aggregate as their distribution in mix is wider and more uniform. [4] Moreover it offer 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, only a little work has been reported using RA as IC agent in the subtropical region where concrete is more susceptible to curing. To bridge this gap, an experimental study is carried out in hot and dry summer season with an ambient casting time temperature of $30^0 \pm 2^0$C and relative humidity 56 ± 4 percent. From the existing wisdom, concrete produced by using RA as replacement to natural aggregates lead to considerable drop in the vital properties of the concrete viz workability, strength, and durability. To compensate 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, firstly to apparently reduce the water-cement ratio (w/c ratio) and secondly to act as micro-aggregates.
iii. Aggregate form the bulk in concrete and are responsible for all the essential properties of both fresh and hardened concrete. Optimized gradation of coarse as well as fine aggregates help in improving workability and packing of concrete matrix.
iv. Reducing w/c ratio restrains bleeding and shrinkage and 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 to enhance the strength and durability parameters of concrete.

Acute shortage of desired quality and quantity of sand is also not far from reality. It is high time to explore the alternatives without compromising with 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 is 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 fibre is used in the above mix are examined. The study to rediscover the potential use of the discarded material C&D waste, crushed bricks (CB) as a natural sand replacement, and as an internal curing agent shows a promising future for wide applications for sustainable and clean and green environment. Representative results from the study are presented.

Table 1: Contemporary issues in Concrete [2]

To reduce the unhydrated fractions of cement in concrete.
To reduce the use of natural aggregate, whose resources are limited.
To increase the effectiveness of curing.
To improve Interface Transition Zone (ITZ).
To reduce early age shrinkage in concrete.
To maximize the utilization of C and D waste in construction.
To reduce the water footprint in construction.

2. Materials and Methods

A. Material Specification

In the present study ASTM C150 Type I - 43 Grade ordinary Portland cement (OPC) is used. Chemical composition is tabulated in table 2 and basic test results are reported in 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 super plasticizing admixture based on sulfonated naphthalene polymers is used in a fixed dosage of 0.6% (0.6g per 100g of cement) across the study for a desired workability range for all replacements of natural aggregates with RA in the sub tropical climate. As fine aggregate zone-II natural river sand as per IS 383-2013 with an apparent specific gravity of 2.62 is used. For coarse aggregate, 20 mm crushed aggregate is procured from a local crusher. The Fly ash confirming to IS: 3812 (Part-1) used. Distilled water is used.

B. Preparation of materials

A parametric study using proportions given in table 7 with 0.4 w/c ratio with constant cement content and chemical admixture is carried out with three replacements of natural coarse aggregate with RA and sand with CB. *Strategy one* is 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 test 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 w/c ratio and admixture dose; RA of 10-20mm size is bottle necked as suitable replacement for natural coarse aggregate as this size fraction has lesser surface water demand compared to lower sizes. Further, intentional use of rounded natural aggregate of size 4.75- 12.5 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 workability stand point 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 replacement. The properties of coarse and fine aggregates are as per table 4.

Table 4: Properties of Aggregates

Properties	Coarse aggregate			Fine aggregate
	Normal Aggregate (NA)		Recycled Aggregate (RA)	
	20-10 mm	10-4.75 mm	20-10 mm	
Specific gravity	2.72	2.70	2.63	2.62
Water absorption (%)	0.5	0.58	4.62	1.0
Bulk density (Loose kg/litre)	1.39	1.29	-	1.61
Bulk density (Rodded kg/litre)	1.53	1.51	-	1.75
Bulk density (Vibrated Kg/litre)	1.63	1.64	-	1.84
Percentage void (Loose)	48	51	-	38.5
Percentage void (Rodded)	43.5	44	-	33.13

Percentage void (Vibrated)	39.9	40	-	29.77
Crushing Value % IS 2386 part IV	13.85		29.9	---
Impact Value %	8.86		27.6	---

Understandably, RA with 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 2.36-4.75 mm size fraction of CB as an IC agent is the *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 circumstance the quantity of water used in the mix is critical. The average water absorptions of RA and CB are ascertained. The RA and CB as per the mix design are submerged in 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 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 flyash in two size fractions: 90 microns passing and 90-150 micron flyash is used as micro aggregates. Use of additional fly ash imparts multifold benefits to the concrete mix, it is the cheapest way to increase paste content, prevents bleeding, shrinkage, imparts later age strength, better packing and durability. The quantity of 90 micron passing fly ash is ascertained by apparently lowering the w/c ratio of mix using fly ash instead of additional cement the calculation is shown in Table 5. 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 fly ash to be used in each mix is quantified by lowering the w/c ratio from 0.4 to 0.38 and 0.36 by adding 90 micron passing fly ash instead of cement the calculation is shown in table 5.

Table 5: Qty of Fly ash for apparently lowering w/c ratio

As Per Mix Design			(Qty of water in mix/ Target w/c ratio - Cement Content)*100/ Cement content	Target w/c ratio	
				0.36	0.38
W/C ratio	Cement content	Water		Fly ash % required	
0.4	400	160		11.11	5.26

B.2. Quantity of Internal curing agent required for Internal Curing

To calculate the dry mass of IC agents required in the mix Bentz & Snyder [5] equation is used. The equation is based on the principle of supply and demand which involves 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.

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

Where:

M_{RA} = mass of (dry) recycled aggregates per unit volume of concrete (kg/m^3); Cf =cement content (kg/m^3); CS = 0.7 [3] chemical shrinkage of cement (g of water/g of cement); α_{max} = maximum expected DoH of cement; S = 1 degree of saturation of aggregate (0 to 1); and φ_{RA}= absorption of recycled aggregates kg water/kg dry recycled aggregates.

Correct approach for the value of Φ is to use the measured desorption capacity of IC agent at 92% relative humidity.[5]

Table 6: $M_{RA,}$ Mass of dry Recycled Aggregates (RA) & Crushed Bricks (CB) required

egree of Hydration	φ_{RA}, Absorption of RA = 4.6%,		φ_{RA}, Absorption of CB = 12.24%,	
	Qty of natural aggregates (NA) in mix (as per mix design)= 1196.8 kg/m^3		Qty of natural sand in mix (as per mix design)= 667 kg/m^3	
	w/c ratio= 0.4, CS= 0.7, Cf= cement content = 400kg/m^3			
α_{max}	$M_{LWA,}$ Mass of dry RA required kg/m^3	%age replacement of NA	$M_{LWA,}$ Mass of dry CB required kg/m^3	%age replacement of Sand
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

All ingredients are stored in room temperature. 256 cubes of size 100x100x100mm are casted, cured and tested for determining 7, 28 and 56 days compressive strength. 96 beams of size 500x100x100mm are casted, cured and tested for 28, 56 days flexural strength. Moulds coated with an anti-adhesive substance are filled and compacted. The samples are demoulded after 24 h, and then suitably cured. Since fly ash is used proper and longer curing is ensured for favorable results.

C. **Experimental Studies**

C.1. Fresh concrete properties

Experimental study carried out on fresh concrete are - slump cone, compaction factor, rheology, shrinkage and electrical resistivity. Schleibinger rheometer EBT-2 is used to study rheology, shrinkage is measured using the Schleibinger Shrinkage Cone deltaEL, Electricity

Resistance Giatec RCON2™ two-probe (electrode) is used to determine the Concrete Bulk Resistivity.

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.2. Compressive Strength

7, 28 and 56 days compressive strength is determined as per ASTM C39/C39M using 100mm concrete cubes specimen, the rate of loading applied is 140 kg/cm^2 per minute till the specimen fails. The compressive strength of concrete is the failure load divided by the cross sectional area.

C.3. Flexural Strength

The 28d and 56d flexural strength test is performed as per ASTM C78/C78M–16 using simple beam with third-point loading, Spacing of the supports is 300 mm.

C.4 Electrical Resistivity

Bulk Electrical Resistivity Test (ER) is carried as per ASTMC1202. The fully saturated cubes are placed in between two parallel metal plates with moist sponge of ER meter. The voltage between two ends of the specimen is measured by applying small alternating current at intended frequency. The impedance Z is displayed on the monitor of ER meter. Concrete resistivity is then determined using equation (2):

$$\rho = \frac{A \times Z}{L} \quad (2)$$

Where, ρ is the resistivity of concrete (Ωcm), A (cm^2), L(cm) are the cross sectional area and length of specimen. Z denotes impedance measured by device (Ω).

C.5. Microstructure Investigations

To examine the effects of IC using RA as an IC agent and to ascertain the transport and durability properties of this sustainable modified concrete micro structure investigation is justified. For the investigation Zeiss make Scanning Electron Microscope (SEM) equipped with a chemical compounds analysis system based on Energy Dispersive Spectrometry (EDS) is used. SEM observations are examined on 119 days samples. Small specimens of size around 4-5 mm are extracted from fractured concrete cubes, the surface of the specimen is polished and mounted on gold splutter coater for gold coating and mounted on aluminum stub for scanning the image at high resolution. The SEM images of different mixes are taken at various magnifications as per the requirements of our study. [6]

C.6. Carbonation

Three air dried 56 days cured cube specimen of each mix are placed in carbonation chamber such that the circulation of air in not restricted. The chamber is set at a constant temperature of 33^0C and humidity 70% rate of carbonation is set to 5%. The reason for selecting higher temperature is to simulate sub tropical climate. An accelerated carbonation is carried out for 60 days and the phenolphthalein test is used to measure carbonation depth. Phenolphthalein solution as required is procured from local market. The cubes are fractured using compression testing machine and the inner surface is cleaned of dust and loose particles. The Phenolphthalein solution is sprayed over the fractured concrete surface. Phenolphthalein is a colorless acid indicator which turns pink when the concrete is alkaline, that is when the pH more than 9.5. No change in color indicates that carbonation has taken place and the carbonation depth can be measured from the surface [7].

C.7. Degree of hydration

Estimating the exact Degree of Hydration (DoH) in concrete produced using RA is complicated. The pieces of 28 days fractured cubes are soaked in acetone to stop the hydration reactions. On the day before the test the acetone is removed and the samples are dried at 60°C in an oven for 24 h and are ground to pass through 150 micron sieve. To determine the non-evaporable water, [8] first calculated the LOI, then Wn and then DoH is calculated. To determine LOI 5g of 150 micron passing grounded sample is ignited at 950°C in an electric furnace for 1 h. The loss on ignition (LOI) of the hydrated cement pastes is calculated by equation (3):

LOI(%)=100x(wt of sample–ignited weight)/ignited weight (3)

The content of hydrated paste, Wn is determined by oven drying 5g of the powdered hydrated sample at 110°C for 3h in an oven, and then ignited at 950°C in an electric furnace for 1h. The Wn is calculated by using equation (4):

Wn(%)=100x[(wt. of dried sample–ignited wt. of sample)/(ignited wt. of sample)– LOI] (4)

The hydration of 1 g of anhydrous cement produces 0.23 g of Wn.[9]. The DoH (%) of the cement in the sample is = 100 x Wn/0.23

3. Results and Discussion

The prime objectives of the study is to improve 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 control mix in table 8-9, 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 as properties of fresh concrete, 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 function of various factors. Using C&D waste as replacement of 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 controlled bleeding by the use of fly ash and internal curing action. In the study, using strategies resulted in a medium workable mix which 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% FA+0.2%GF	1.81	6.57	4.53	5.78	5.81
20.34% RA+20.99%CB+ 11.11% FA+0.2%GF	3.54	9.2	6.66	8.36	8.76

The fracture of concrete specimen with 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 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 days compressive strength of all the mixes with RA and additional fly ash is observed to be greater than the control mix. 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 flexural strength of the composite as per expectation. To ensure a strong and durable concrete using a marginal material a nominal dose of glass fibre is used resulted in 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 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 reduce its pore size thus the capillary pull which is inversely proportional to 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 researches. The combined action of additional fly ash and IC mechanism in concrete restraint 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 is desirable from durability stand point. Glass fibre 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.

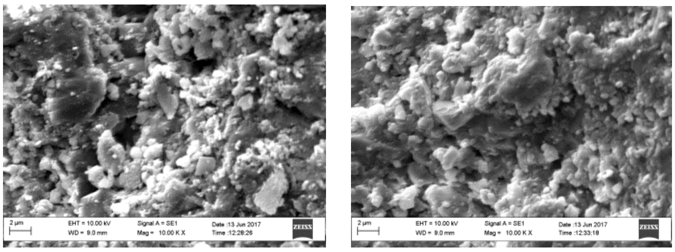

Fig.1: SEM images of 28days cured concrete with crushed bricks as an internal curing agent and an additional dose of fly ash (0.4 w/c ratio)

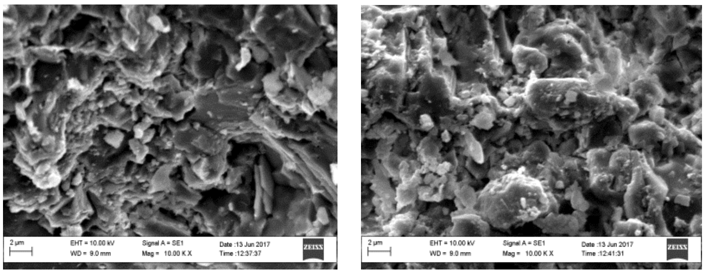

Fig.2: SEM images of 28days cured control concrete and concrete with crushed bricks as an internal curing agent and an additional dose of fly ash (0.4 w/c ratio).

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. Use of fly ash in concrete proposes an increase in the carbonation depth but 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 effective w/c ratio with increasing percentage of fly ash in the matrix. Further, higher DoH should result in higher chemical shrinkage, but in the present study, use of multiple strategies successfully restrained shrinkage in spite of increase in DoH.

4. Conclusion

The multiple strategies discussed in the paper has 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 concrete using recycled aggregates for field and practical implementations without compromising with the vital properties of concrete. Use of an abundantly available industrial byproduct fly ash as a sustainable and cheap admixture to reduce shrinkage and bleeding is also recommended for increasing the carbonation resistance of internally cured concrete with higher degree of hydration. The unhydrated fraction of fly ash is influential in offering a well-packed matrix with low porosity which is essential for durable concrete with higher predictability of service life at a nominal cost. Simultaneous application of a nominal dose of glass fibre 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 combined action of both internal and external curing without at 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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