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For Parametric Study of Sustainable Concrete Produced using Marginal Material as an Internal Curing Agent for Partial Replacement of Natural Sand in Subtropical Climate of Central India

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ABSTRACT

The paper is an attempt to address some of the issues of modern civilization like solid waste management of debris of Construction and Demolition waste, identifying alternatives for fast depleting natural sand, and the scarcity of water for construction purpose in the various fast-developing cities. In central India, the cluster of Chhattisgarh, Maharashtra, Madhya Pradesh and Odisha together are the largest manufacturer of low lime-fly ash in the country. The previous works on the use of construction and demolition waste in concrete as alternatives to aggregate have reported a loss in the vital properties of concrete. The research plan presented in the paper looks to extend beyond these confined results and explore the possibility to produce strong and durable concrete using marginal materials by sustainable strategies. On integrating the two problems a solution for concrete is obtained using construction and demolition waste crushed bricks as internal curing agent thus improving the efficiency of external curing and using fly ash for improving microstructure, strength, and durability of concrete. The paper also intends to share the core idea and the methodology of the research work so that better and wider alternatives of the proposed model will be tested and reported for the interest of the Nation at large and the region in particular. Considering the fact that India is being rebuilt small sustainable efforts like these can have significant impacts in saving natural resources, create space in cities, reduce carbon footprints, and reduce environmental impact. Thus partnership is invited from the practitioners to carry the findings of research beyond the boundaries of laboratories to practical field applications.

Keyword: *Internal Curing(IC), Construction and Demolition (C&D) Waste, Interfacial Transition Zone (ITZ), Microstructure.*

1. INTRODUCTION

The construction sector is the second largest contributor to the economic activity, after agriculture, in India. The Indian construction industry is expected to have an annual growth rate of 7-8% over the next 10 years. These are riders of responsibility on Indian researchers to synchronize with the state-of-the-art apt technology which is both sustainable and suitable to the Indian context. The flagship projects of Government of India like rehabilitation of the slums, 100 smart cities, metro projects and industrial corridors where Trillions of INR is at stake for their successful implementation and completion, the practice of recycling and reuse is highly recommended for substantial savings. [22]

1.1 Impact of C&D Waste

Fast Urbanization demands efficient land utilization. To accommodate more population, floor area ratio is increased causing the demolition of existing structures for reconstruction. For various upcoming and ongoing the existing structures which have not yet completed their intended life are to be demolished. The quantum of debris produced in the demolition of these structures is huge and their suitable disposal is a challenge for municipal bodies. Good engineering practice advocates, for recycling and reuse of such material. The reuse of C&D waste has potential to save natural resources, reduce CO2 footprint, reduce other environmental impacts thus creating space in urban areas, reducing large space required for dumping sites. This would also lead to the creation of ample business opportunities. The illegal dumping and unplanned disposal of these C&D waste are causing severe ecological and environmental problems. Huge heaps of C&D waste causes rise in flood levels of the rivers, scouring of the banks, depletion of resources, leaching out of hazardous material in the water causing an impact on aquatic life. These wastes when buried on the site, form impervious layer which affects the growth of vegetation and prevents infiltration of rainwater. Concrete, brick, ceramic and mortar together constitute around 80% of the total C&D waste which is in a mixed form and needs segregation and processing before application. The point of biggest concern is that till date the authorities of all the cities in India are not having the exact and reliable data of the city wise, district wise, state wise quantity of C&D waste and their subdivision that is being generated every year. The data of C&D waste generation and disposal records of past are also not available. However, the actual data collection process has begun across India. [4][5][6][7][8][9][22].

1.2 Sustainability Issues with Ingredients of Concrete

The next generation concrete should be sustainable; as today concrete is the world's most used known material after water and will continue to be an integral part of the construction industry. All the basic ingredients of concrete like cement, aggregates, and water all have some or the other environmental effects. The cement production is one of the top contributors to the Greenhouse gas in the world. The aggregates used as fillers in the concrete are all virgin materials in the form of natural sand or disintegrated rocks. [1][2] For producing and curing concrete huge quantity of fresh water is used. The scarcity of desired quality and quantity of natural sand and water has led to stringent impositions by Municipal Corporation on their use for construction purpose in many big cities. It is high time to find a suitable replacement of sand without sacrificing the basic properties of concrete. The fact remains that no material is waste, only its suitable use has not been identified.

1.3 Curing the Easiest Way to Improve Properties of Concrete

Curing is the process of controlling moisture movement from and into the concrete during hydration of cement. "Concrete must be properly cured if its optimum properties are to be developed. An adequate supply of moisture is necessary to ensure that hydration is sufficient to reduce the porosity to a level such that the desired strength and durability can be attained and to minimize volume changes in the concrete due to shrinkage". [1][2] Considerable early age drying shrinkage is seen in the concrete that dries out quickly and is the principal factor for producing weak concrete with powdery surfaces with low abrasion resistance. Inadequate curing increases permeability and absorptivity which in turn affects the durability of concrete. Further, the permeability and absorptivity characterize the durability of concrete which are a function of porosity of the concrete. Long-term performance and durability of concrete depend whether the pores are discrete or interconnected. Water-cement ratio and effectiveness of curing define the quantity, size of the pores and capillaries in cement paste. Effective curing considerably reduces the porosity of the cement paste, as the pores and capillaries are partially or completely filled up with the hydrated products. [1][2][3].

1.4 Present Scenario of On-Field Curing

As discussed above the long-term performance of concrete primarily depends upon the effective curing but due to lack of awareness or situational circumstances in the site, early age curing lacks due attention in Indian construction industry. This results in a considerable fraction of unhydrated cement in the matrix which leads to the underperformance of concrete thus depriving the industry of the maximum expected potential of concrete. Also, the external field curing methods are tedious, labour intensive and unsustainable as it causes a lot of water wastage due to evaporation and runoffs. This wastage of water at the site should be checked and efforts should be made to improve the efficiency of on-site curing. External curing water is applied to the surface figure 1 and its depth of penetration and effectiveness is influenced by the quality of the concrete. Due to the reduction in permeability of concrete, in the first 2-3 days, external water curing is limited in its ability to supply in-depth hydration to the cement as the products of hydration fill in and disconnect the capillary pore network. [11]

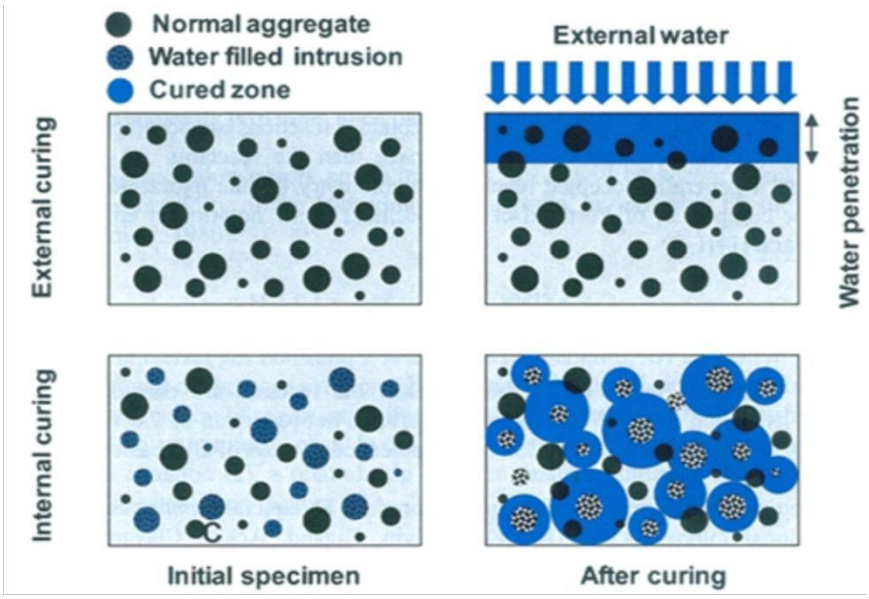

Figure 1: Illustration Internal vs External Curing [11]

1.5 Internal Curing

Internal curing has drawn the attention of many concrete researchers across the globe in the first decade of this century. Internal curing complements the conventional curing to increase the effectiveness of curing and making concrete more durable and less permeable by better hydration and lesser shrinkage. As per the ACI-308 internal curing is defined as, "Internal Curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water." [3, 11, 22] IC supplies the extra curing water throughout the concrete mix thus maintaining the relative humidity (RH) and avoids self-desiccation and thus restrains autogenous shrinkage. IC also works well with Supplementary cementitious material like fly ash. IC is also effective in addressing the complex issues of concrete like shrinkage, vulnerable ITZ, un-hydrated cement fraction due to lack of proper curing and durability issues arising from microcracks due to varied reasons. [12-17].

The effectiveness of IC depends on three factors: i. the quantity of water IC agent can hold (absorption capacity of agent). ii. The quantity of water it can release (desorption capacity) to the desiccating mix around. iii. Dispersion in the matrix. Crushed brick is having water absorption capacity greater than 10% and its pore sizes are also slightly larger than that of the pore sizes of cement paste mortar matrix around it. For IC mechanism pore size of the IC agent acting as an internal micro water, reservoir should be larger than that of the mix around it. This is an essential requisite for the capillary pull of absorbed water from IC agent to the desiccating mix around having smaller pore sizes.[12-17, 22] The use of marginal material crushed brick which is not an efficient IC agent as compared to other pre-soaked lightweight aggregates is debatable. However, it should be realized that sustainability is priceless.

1.6 Fly Ash Utilization in the Chhattisgarh State of India

As per the report [23] on fly ash generation at coal/lignite based thermal power stations and its utilization in the country for the year 2015-16. Chhattisgarh is generating 24.2256 million tonnes of fly ash and utilizing merely 7.9196 million tonnes (32.69%) per year. As per the Annexure II of the same report utilization percentage of fly ash in making concrete is zero [23]. This is alarming considering the fact that Chhattisgarh state is ranked second in coal production and has 16% of the total coal deposits of India. This calls for synchronized efforts of concrete technologists and practitioners of the region in particular in wake of the cause. From the literature review, it is clear that Fly ash has multi folds benefits on various properties like workability, strength, and durability. It is high time that the use of fly ash in Chhattisgarh is not limited to manufacturing of fly ash bricks only. When the researchers have already tested and reported using of high volume fly ash in concrete for producing high strength and high-performance concrete efforts should be made to utilize fly ash in the making of concrete also in Chhattisgarh and nearby areas.

Sl. No.	Name of State	Nos. of TPS	Installed Capacity (MW)	Fly Ash Generation (Million-tonne)	Fly Ash Utilization (Million-tonne)	Percentage Utilization %
1	2	3	4	5	6	7
1	ANDHARAPRADESH	8	10310.00	17.5277	10.4779	59.78
2	BIHAR	4	4100.00	6.3442	2.1763	34.30
3	CHHATISGARH	19	15790.00	24.2256	7.9196	32.69
4	DELHI	2	840.00	0.5268	0.6879	130.59
5	GUJARAT	11	15212.00	6.6311	6.4125	96.70
6	HARYANA	5	5987.80	5.0474	5.7471	113.86
7	JHARKHAND	7	5307.50	7.0382	6.3759	90.59
8	KARNATAKA	4	4780.00	4.7803	2.3554	49.27
9	MADHYA PRADESH	6	9540.00	13.4212	3.9963	29.78
10	MAHARASHTRA	20	18936.00	18.6383	13.0005	69.75
11	ODISHA	5	5188.00	10.9490	5.3974	49.30
12	PUNJAB	3	2640.00	1.9053	2.0747	108.89
13	RAJASTHAN	7	6640.00	6.1136	5.7856	94.63
14	TAMILNADU	13	10350.00	8.4443	6.7062	79.42
15	TALANGANA	4	1882.50	2.9921	0.8703	29.09
16	UTTAR PRADESH	17	15464.00	24.6277	11.1182	45.15
17	WEST BENGAL	16	12077.00	17.5313	16.6641	95.05
	GRAND TOTAL	**151**	**145044.80**	**176.7441**	**107.7658**	**60.97**

Figure 2: State Wise Fly Ash Generation and Its Utilization during the Year 2015-16

1.7 Research Objective

The central idea of the present study is to recycle and reuse the construction and demolition waste (C&D) for producing internally cured concrete without sacrificing its vital parameters which is viable from both laboratory research scale as well as for field practical implementation. Partial replacement of natural sand with C&D waste marginal material presoaked crushed bricks is sustainable and using it as an internal curing agent in subtropical climate is innovative which will incorporate the benefits of internal curing into the concrete. The five essential parameters of modern concrete taken care off in the study: are workability, strength, durability, microstructure, and sustainability. Durability is considered as the vital parameter as the service life of concrete is associated with it.

Figure 3: Vital, Essential and Desirables of Concrete

2. RESEARCH SIGNIFICANCE

Today, the focus of the concrete technology fraternity is mainly on the durability and service life of the concrete. In the last decade extensive research on IC, using various pre-wetted lightweight aggregate and the super absorbent polymer has been carried out.[12-17, 22] However, only a little work has been reported using crushed bricks as IC agent in tropical and subtropical climate region. To bridge this gap in the existing database of knowledge, this experimental research is designed. 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. [21, 22]. Recycling and reuse of materials save a huge amount of natural resources that reduce CO2 footprint and also reduce its impact on the environment. It is inevitable to develop sustainable technologies and to reduce carbon footprints. The dual uses of class F fly ash are, firstly to apparently reduce the water-cement ratio (w/c ratio) and secondly to use as micro-aggregates are the features of the study. The parametric investigation of the combined effects of crushed bricks as an IC agent, fly ash in a dual role and their interface with glass fiber, on the various properties of concrete, in subtropical climate is the main differentiator. The outcome of the study is a simple, sustainable multi-fold strategy model to produce better concrete using marginal materials. The schematic flow chart of the methodology and target findings is depicted in figure 4, 5, 6.

3. RESEARCH METHODOLOGY

To achieve the objectives of the study the laboratory experimental research design is established to develop a credible cause-and-effect relationship amongst the variables and the parameters by manipulating the variables. For the parametric study suitable tests are identified which are available and accessible in our lab shown in figure 4. All the experiments are to be conducted with a high level of control and reliability as per the guidelines of various codes.

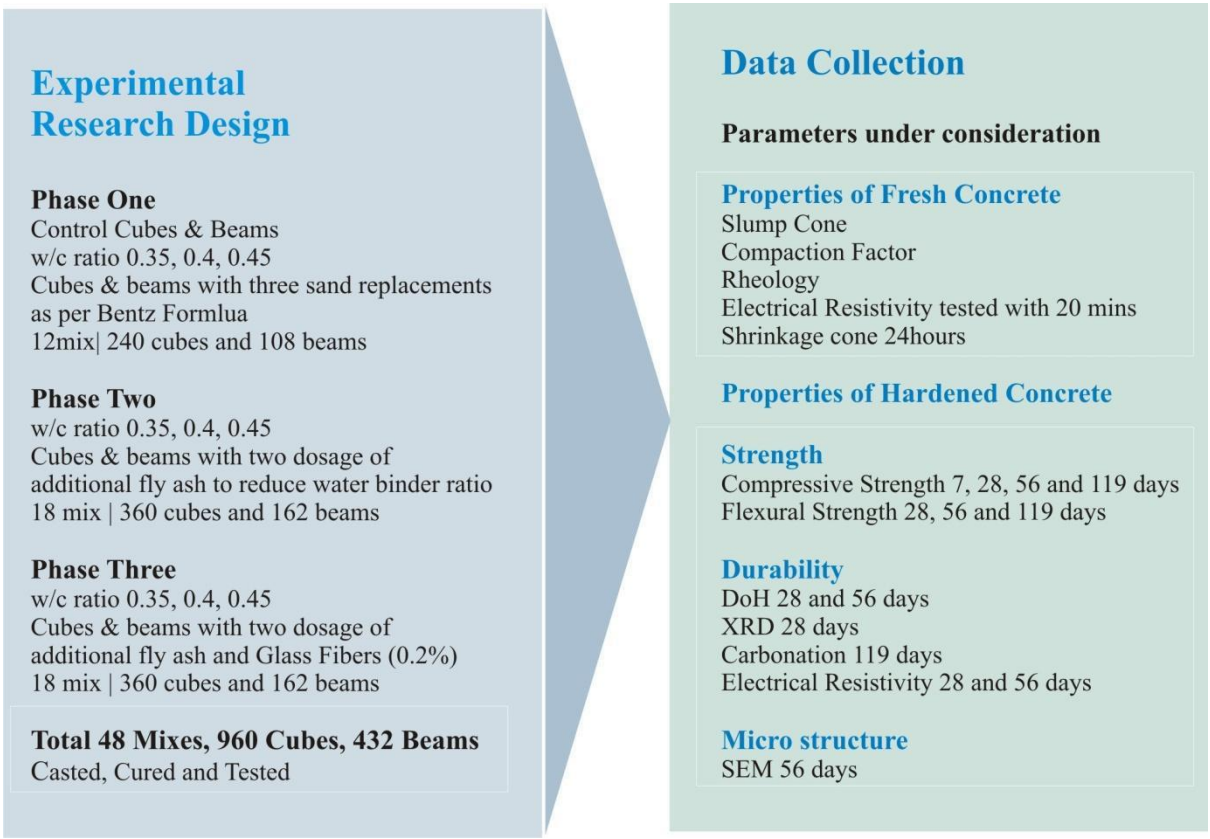

Figure 4 Target Findings of the Study

The basic tests on the properties of materials like Portland cement, fly ash, sand, coarse aggregate and crushed bricks are conducted in compliance with IS guidelines. In phase one to map the effect of replacement of fast depleting natural sand with pre-soaked crushed C&D waste bricks as an internal curing agent, three w/c ratios are used. Cement concrete cubes and beams with different w/c ratios and percentages of sand replacements with crushed bricks will be cast, cured and tested up to 119 days along with other parameters. The shrinkage, Degree of Hydration (DoH) [19] and Electrical Resistivity (ER) results will validate the functioning of internal curing mechanism within the concrete. Based on the literature review marginal decrease in vital concrete properties like workability, compressive and flexural strength is expected and are major issues at the end of phase one.

In phase two, to make up for the loss of workability, compressive and flexural strength of concrete due to the replacement of sand with marginal material crushed bricks as an internal curing agent, another sustainable strategy of using additional fly ash will be adopted. It may be noted that neither cement nor sand is to be replaced with fly ash. Two dosages of additional fly ash as per calculation in each w/c ratio will be used. To understand the effect of additional fly ash on various parameters of internally cured concrete cement concrete cubes and beams with same w/c ratio and corresponding percentages of sand replacement with crushed bricks used in phase one, 18 mixes are to be cast, cured and tested up to 119 days along with other parameters. Satisfactory improvement in workability and compressive strength of concrete is expected however the early age strength of concrete will be an issue. Packing of the matrix is also expected to improve substantially, durability indexes like ER, DoH, and carbonation [10,14] will validate the improvement in durability. The flexural strength is also expected to improve marginally however it is unlikely that flexural strength will be at par with the control mix.

In phase three, to enhance the flexural strength of internally cured concrete with pre-soaked crushed bricks as a sand replacement, Glass Fiber in a single dose of 0.2% by weight of cement will be tried. 18 mixes are to be cast, cured and all the parameters will be tested. The test results on beams will confirm the desired enhancement of flexural strength in internally cured concrete using crushed bricks with an additional dose of fly ash and a nominal dose of glass fiber. The other tests like Slump cone, Compaction factor, Rheology, Shrinkage cone, Electrical Resistivity(ER), Degree of Hydration (DoH)), XRD, SEM [18] and Carbonation will also be carried out simultaneously as per the research plan. Data will be accumulated and synthesized. Step by step process is illustrated with the help of a flowchart in figure 4.

3.1 Mix and Sample Production Process

The entire study is to be carried out at an ambient lab temperature of 330C + 30C and RH less than 60% during mixing and casting which is in line with a sub-tropical climate. Since additional Fly ash is being used proper and longer curing is ensured for favorable results. From literature review it is clear that to make a strong and robust concrete good packing is essential; both maximum density and minimum voids tests are conducted for various mixes based on which coarse aggregate (CA) (12.5-20mm) to CA (4.75-10mm) ratio is decided[21].

From which following parameters are decided:

i. Based on the tests conducted on the available materials CA (20mm) to CA (10mm) ratio in the mix is decided as 53% (10-20mm) and 47% (4.75-10mm). Numerous trials for maximum density are conducted using the available materials. (Strategy 1)

ii. Three natural sand replacements with crushed bricks (CB) are evaluated in the present study for each w/c ratio using 1% super plasticizer. High dose of SP is used to achieve minimum desired slump of 55mm in all the mix (CB+FA+GF) in a subtropical climate. A lower dose of SP can also be used.

iii. When the focus of the study is to improve the strength, durability, and microstructure of concrete which are functions of w/c ratio. The quantity of water in the mix should be calculated and handled carefully as pre-soaked crushed bricks are being used as an internal curing agent. For calculating the actual quantity of water in the mix, the quantity of water, CA and CB required as per the mix design is calculated and water absorption of CB is also determined. The required quantity of CB is submerged in a known quantity of water for 24 hours in a closed container ensuring that there is no loss of water. The entire submerged CB with water is poured in the mixer along with CA and sand. The known quantity of water used for immersing CB is deducted from the final count of water in the mix. The total quantity of water used in the mix is equal to the quantity of water as per the mix design plus the water absorbed by the CB. (Strategy 2)

iv. For IC the contemporary practice is to use fine aggregate as an IC agent, their distribution in the mix is more uniform and they effectively cover the entire mix. The crushed brick size 2.36mm- 1.18mm is used as an IC agent in the study. (Strategy 2)

v. The fineness of FA is a key factor in its pozzolanic effect, in present study additional 90 microns passing FA is being used intended for pozzolanic action, the unhydrated FA will remain in the mix as a filler material referred to as micro-aggregates will help in better packing and durability. (Strategy 3)

vi. The mixing process of IC concrete and conventional concrete is more or less the same.

vii. Quantity of fly ash used

For the sake of computation of the quantity of FA to be used in each mix, the calculation is made by keeping cement content constant as per the mix design and stepping down the w/c ratio in a count of 0.02 by using additional 90 microns passing FA.

Fly Ash required for apparently lowering w/c ratio = [(Qty of water in mix/ Target w/c ratio) - Cement Content]*100 / Cement content (1)

viii. Quantity of CB aggregate required for IC

Bentz et.al., 1999 [13,15] eq. (2) used the simple Principle of Supply and Demand to estimate the volume of IC water required and the corresponding mass of IC agent. The volume of chemical shrinkage is approximated as the volume of water that needs to be supplied by the IC agent.

(2)

Where: M_{ICA} = mass of (dry) fine internal curing agent needed per unit volume of concrete (kg/m3)

Cf = cement factor (content) for concrete mixture (kg/m3)

CS = chemical shrinkage of cement (g of water/g of cement)

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

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

φICA = absorption of internal curing agent (kg water/kg dry LWA).

The correct approach to the value of Φ_{ICA} is to use the measured desorption capacity of the ICA at 92 % RH. As in reality, the ICA is "saturated" initially and then undergoes desorption during IC. (Bentz et.al.2005) [16]

Table 1 Chemical Shrinkage Due to Cement Phase [11, 12]

Cement Phase	Coefficient water/Solid cement phase (g/g)
C3S	0.0704
C2S	0.0724
C2A	0.171*, 0.115**
C4AF	0.117*, 0.086**
Silica Fume	0.2

Assuming sufficient sulfate to convert all of the aluminate phases to ettringite *
Assuming total conversion of the aluminate phase to monosulfate

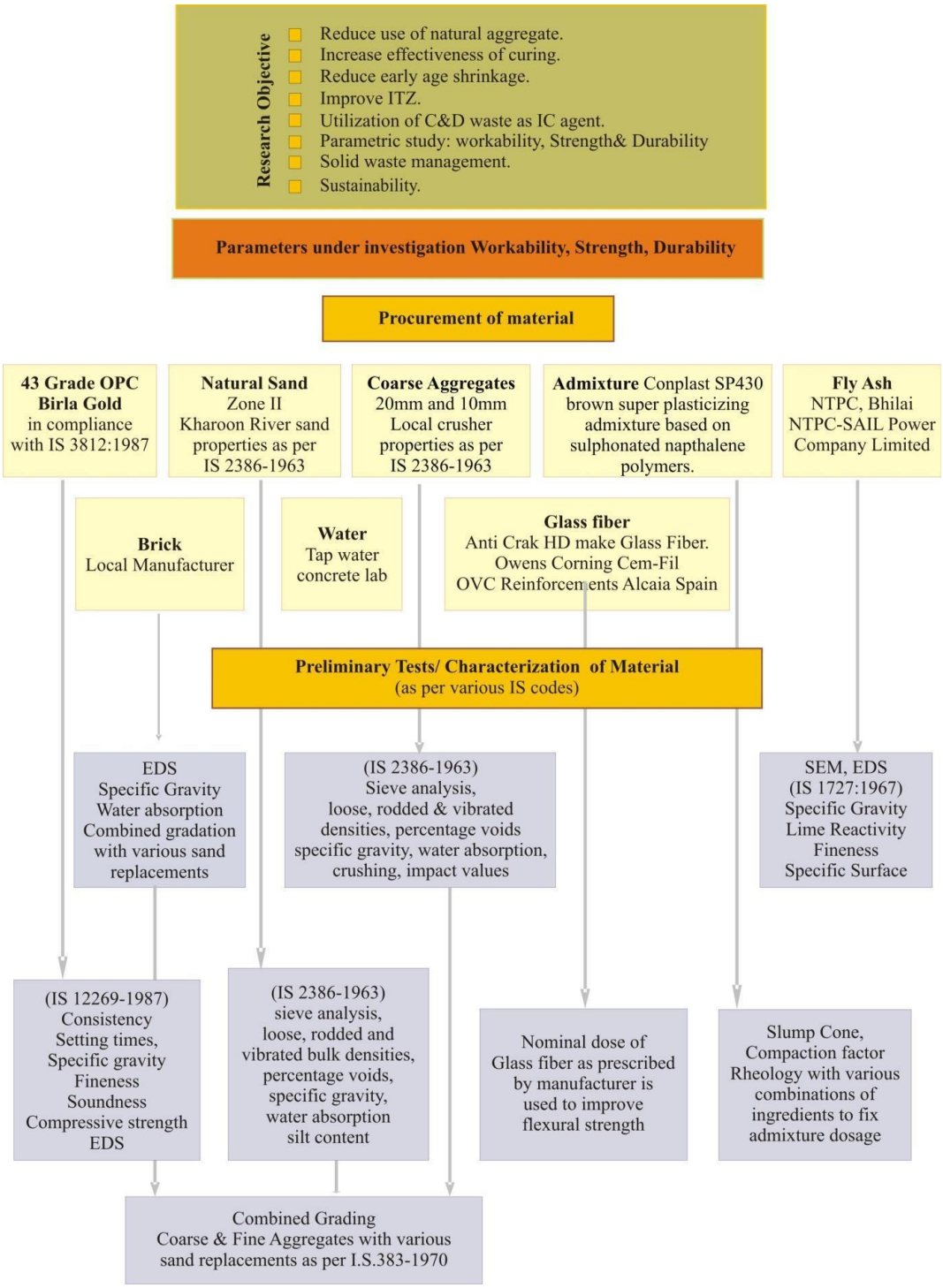

Figure 5 Flow chart of Research Methodology

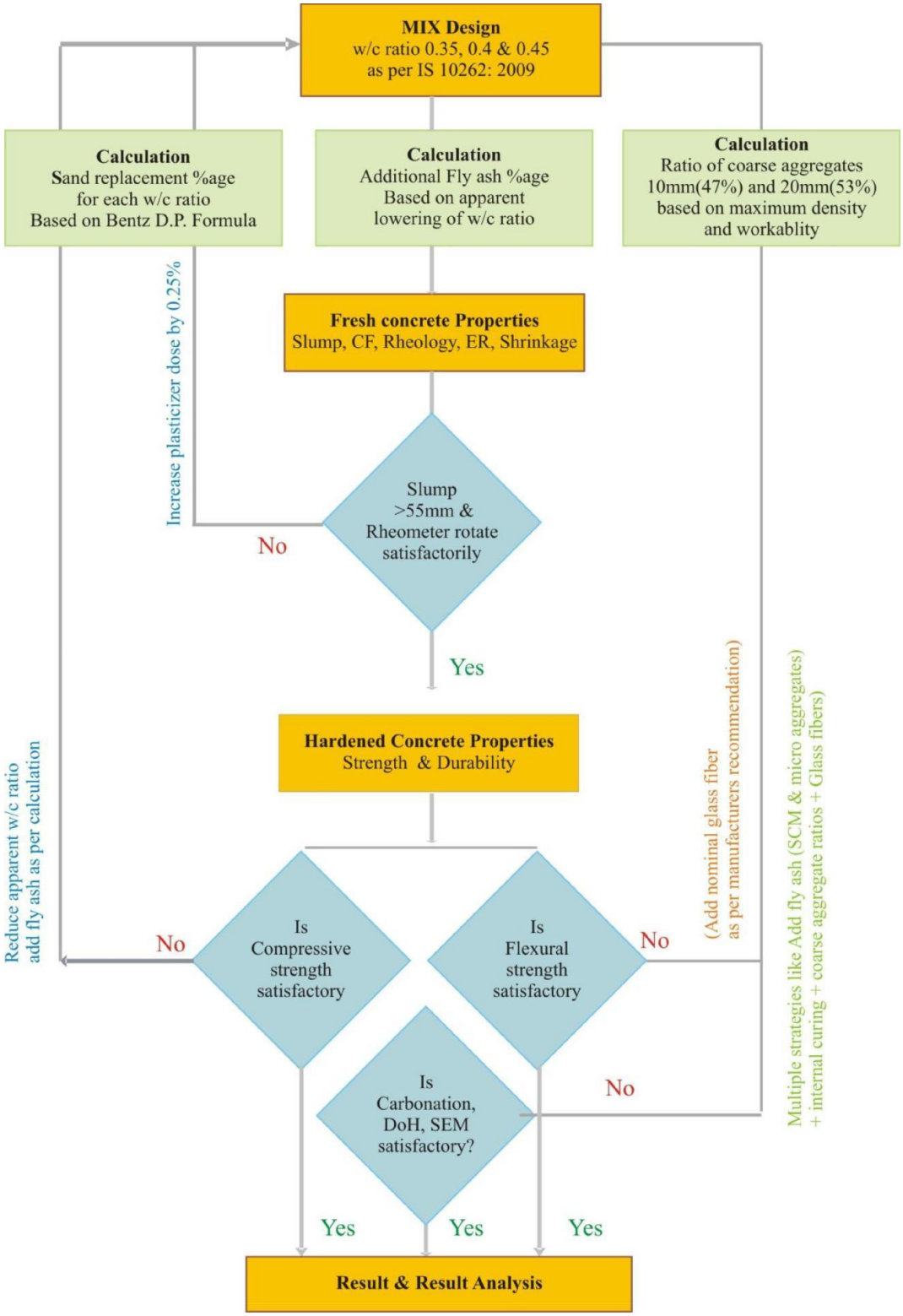

Figure 6 Flow chart of Research Methodology

4. CONCLUSIONS

A model for producing workable, strong, durable, sustainable concrete with improved microstructure using C&D waste crushed bricks for natural sand replacement and industrial by product Fly ash for multifold benefits to the construction industry and society as well is presented. On the basis of various test results valuable multi correlations between w/c ratio, %age of sand replacement with marginal materials like crushed bricks, %age of flyash and glass fiber will evolve which will enable wider applications of the strategies applied to make up for the loss in vital properties of concrete – workability, strength and durability.

Table 2. Qualitative Effects of Using Multiple Strategies on Various Parameters of Concrete

Parameters	Status of concrete with RA	*Strategy1* Adjusting CA to CA ratio	*Strategy 2* Application as IC agent	*Strategy 3* Lowering w/c the	*Strategy 4* Using Glass Fiber
Workability	Poor	√√	√	X	X
Strength	Poor	√	√√	√√	√√
Durability	Poor	√	√√	√√	√√
Micro Structure	Poor	√	√	√√	√√
Sustainability	Good	-	-	√√	-

√ Marginal improvement, √√ significant improvement, X no improvement, - no effect

Precaution of handling water in the mix is strongly advised otherwise results may be disruptive. There is a need to commercialize the demolition and C&D waste material handling process this can also lead to small-scale business opportunity. The study will also extend the benefits of Internal curing to the concrete thus enhancing the effectiveness of external curing in the sub-tropical climate of central India using locally available materials. The study is just a humble attempt to examine the issue of solid waste management and their sustainable use in concrete; other, much better approaches are yet to come. Use of costly materials like glass fiber and a high dose of plasticizer may also be criticized. Figure 7 is a self-explanatory illustration of various expected outcomes at various phases of the study.

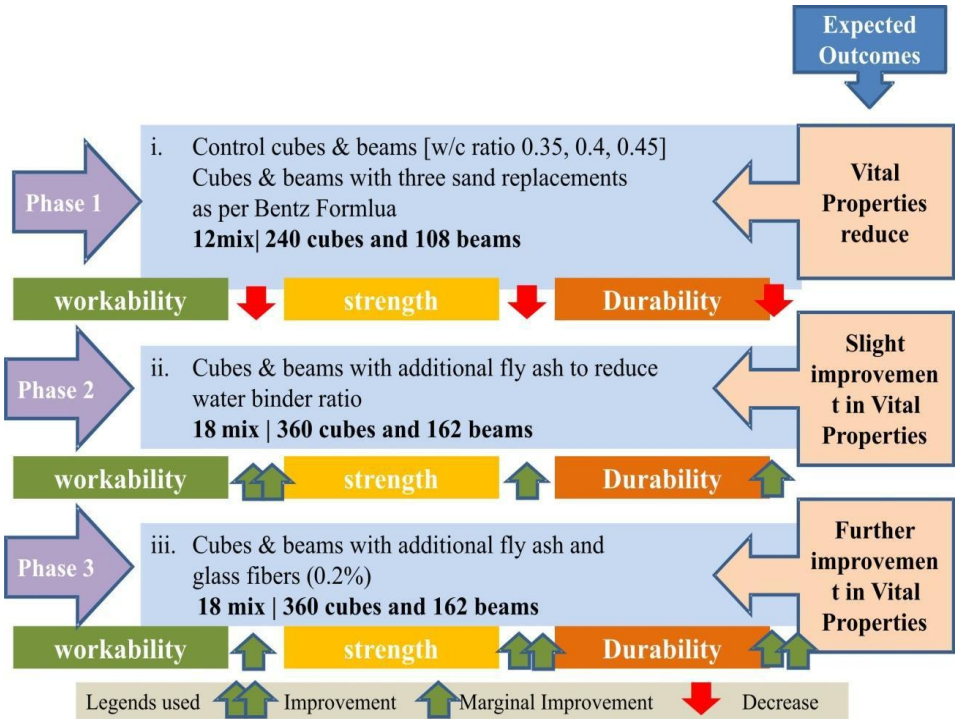

Figure 7 Phase Wise Expected Outcomes of the Study

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