A Review on: Utilization of Recycled and Waste Materials in Construction Applications

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ABSTRACT

In order to move towards a sustainable construction, it is relevant to implement waste management policies in the construction sector that promote closed-loop material cycle. In this context, utilization of wastes as secondary construction materials represents an important path to reduce the extraction of huge quantities of primary raw materials. The continuous global demand for infrastructure due to persistent increase in population growth implies that more aggregate would be required in concrete production. In concrete construction, aggregates are one of the main ingredients in producing concrete that covers 75% of the total concrete. This would eventually lead to more extraction and depletion of natural resources and increased carbon emission.More production equals more waste, more waste creates environmental concerns of toxic threat. An economical viable solution to this problem should include utilization of waste materials for new products which in turn minimize the heavy burden on the nation's landfills. Recycling of waste construction materials saves natural resources, saves energy, reduces solid waste, reduces air and water pollutants and reduces greenhouse gases. The construction industry can start being aware of and take advantage of the benefits of using waste and recycled materials. Studies have investigated the use of acceptable waste, recycled and reusable materials and methods. The use of swine manure, animal fat, silica fume, roofing shingles, empty palm fruit bunch, citrus peels, cement kiln dust, fly ash, foundry sand, slag, glass, plastic, carpet, tire scraps, asphalt pavement and concrete aggregate in construction is becoming increasingly popular due to the shortage and increasing cost of raw materials. In this study a questionnaire survey targeting experts from construction industry was conducted in order to investigate the current practices of the uses of waste and recycled materials in the construction industry. This study presents an initial understanding of the current strengths and weaknesses of the practice intended to support construction industry in developing effective policies regarding uses of waste and recycled materials as construction materials.

Keywords: Construction and Demolition waste (CD-W); Recycled fines (RF); Residual cement powder (RCP); Sustainable construction material.

1. INTRODUCTION

Construction activities are inevitable and indispensable for the overall development of society. Also, the environmental degradation associated with constructions is conspicuous. Especially, the dissipating resources of natural sand and limestone are vulnerable for the fulfilment of fine aggregate and cement, respectively. Thus, sustainability in infrastructural development is prime and has to be acknowledged on

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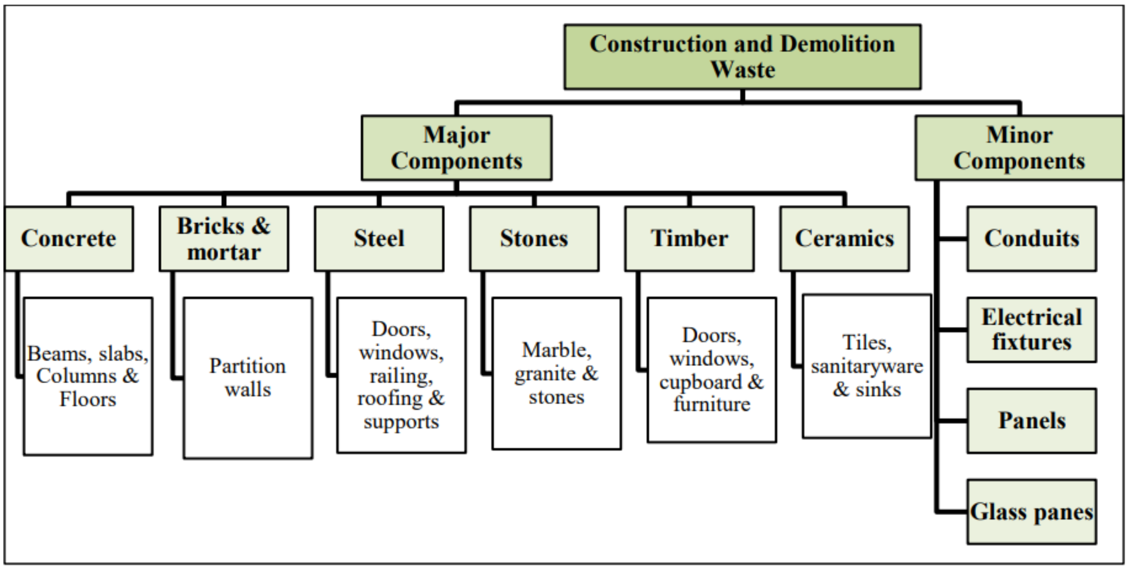
a priority basis to avoid further damage to the must be acknowledged on the environment and natural resources. Many wastes are used as solutions to the sustainable alternative of construction materials, such as fly ash, ground granulated blast furnace slag (GGBS), silica fumes, limestone fines, etc., for cement, and quarry dust, stone dust, copper slag, etc., for sand with limitations. But, construction & demolition waste (CD-W) being the massive of all wastes, has endless potential to alternate construction materials. Several CD-W materials, like metals, timber, wires, asphalt sheets, polymer pipes etc., are already being
are already being reused in construction for lean usages. However, the utility of CD-W for components of structural stability is still irresolute. An approach for productive recycling of CD-W has to be developed, in order to serve needs of fine aggregate and cement, simultaneously. Thus, this dissertation accounted utilization of CD-W to as fine aggregate and cement in mortar and concrete. The major portion of CD-W is used as recycled coarse aggregate (RCA) as coarse aggregate in concrete. However, compromised outcomes of mechanical & durability properties, is the shortcoming of 100 percent utilization of RCA. RCA was found to be underperforming as coarse aggregate due to porous texture, adhered mortar, lower abrasion resistance, and light weightiness. Thus, it was hypothesized, that crushed RCA gives recycled fines (RF), which would be better as crushed recycled coarse aggregate (CRCA) (particle size – 4.75 mm to 150 μm) for fine aggregate and satisfactory as residual cement paste (RCP) (particle size – below 150 μm) for cement replacement, respectively**.** The RF was tested for its physical properties to be in compliance with requirements of sand prescribed in IS: 383, 2016, i.e., Specification for coarse & fine aggregates. However, the chemical composition was determined through conventional testing method and through powder X-ray diffraction (P-XRD) of RF. The comparable chemical composition RF to that of cement (OPC/ PPC) made it suitable for cement replacement. However, the RF particles were found to be heavier and more water absorbing as compared to natural fine aggregate (NFA), which has made it good, but difficult choice for sand replacement. As RF is a known high water absorbing material, the variation in mechanical strengths and durability of mortar and concrete are bound to it. Thus, the study on mortar and concrete was decisive to their behaviour with RF in them under two conditions: first when the slump was kept constant and second when the slump was allowed to vary. To observe the feasibility of RF in concrete and mortar for saving natural non-renewable resources, a scientific approach and series of experiments were performed with various RF percentages. Mortars were tested for flow, setting time, water absorption, and compressive strength, in addition to briquette test, rate of evaporation, change in mass, etc. The test for slump, water absorption, compressive strength, splitting tensile strength, flexural strength, ultrasonic pulse velocity (UPV), bulk density, scanning electron microscopy (SEM) and durability tests were performed concrete. The durability of mortars were tested under acidic immersions of hydrochloric acid (HCl), nitric acid (HNO3) and sulphuric acid (H2SO4), whereas, for concrete the durability under sulphate environment of sodium sulphate (Na2SO4) and magnesium sulphate (MgSO4) was observed. The rapidly growing population has urged the need for infrastructural development. It is high time for the construction industry to rise so that demands can be fulfilled at the right pace. Concrete is the most versatile and prime construction material due to easy mouldability is expected to be consumed at a double rate by 2050 (Peng et al., 2014). Similarly, mortar is in great demand for binding and plastering masonry structures. All the conventional key ingredients of concrete and mortar exploit natural resources such as river sand for fine aggregates, rocks, and gravels for coarse aggregates, lime deposits for clinker of cement, etc. Construction and demolition waste (CD-W) is a potential source that can sustainably assure the

continuous supply of alternate building materials. In the current study, fine aggregates and cement alternatives derived from CD-W are investigated for utilization in concrete and mortar up to 100% replacement of fine aggregate and 20% replacement of cement. This chapter discusses the need for alternative fine aggregate and cements substitutes, requirements of CD-W management, problem statement, and the objective of the dissertation as the solution of the issue and the management has become principle environmental concern with ever-increasing waste. Improper and unauthorised disposal of waste in India is the leading cause to myriad issues. The CD-W generated from ongoing construction activities, impulse renovation work and demolition is accumulating rapidly. Among all the waste generated globally, CD-W is the heaviest and most voluminous waste (Ng and Christian, 2018). Thus, handling of 100% waste generated by urban communities was aimed to be managed efficiently under Swach Bharat Mission of ministry of urban development in 2019 (Central Pollution Control Board, 2017). Figure.1.1 shows the compositions of CD-W. World Bank has projected the global waste generation in 2018 to be 2.59 billion tonnes and 3.40 billion ton by 2030 and 2050, respectively (Singh et al., 2018). However, the situation is getting worse due to poor waste management, which is destroying the land and the environment, collectively in many ways (Kirthika et al., 2019). Major threats to the land, water and health quality can be imposed by the wastes, irrespective of its toxic or non-toxic nature (Singh et al., 2018). Construction waste disposed in landfill takes millions of years to decompose, thus effective strategies and facilities must be designed for handling and recycling waste.



The adverse impacts of leaving unattended masses of CD-W can be broadly classified following categories:

a. Social Impact Usually, bulky and heavy CD-W limits street sweepers and waste collectors to carry. Thus, leftover CD-W creates anaesthetic surroundings, traffic congestions leading to accidents and clogging of water channels leading to epidemics, etc. Also, sharp, broken glasses, boulders, wooden frames, rusted metals, and ceramics of CD-W can cause injury. Sometimes, unsanitary conditions arise, when municipal solid waste is dumped along with CD-W.

b. Environmental Impact Fine dust from CD-W causes air pollution and reduces visibility, and leachate of oil, paints, varnishes, rusted metals, and asbestos sheets degrades soil and pollutes underground water source. Hydrological disturbances and destruction of aquatic ecosystem occurs, when CD-W is dumped on wetlands, water channels, and riverbeds.

c. Economical Impact: Mixed CD-W with municipal solid wastes, increases the cost of waste segregation and processing, which reduces the efficiency of waste recycling. Unplanned disposal of CD-W imposes significant cleaning cost on local government agencies. Also, accommodation of massive CD-W in landfill sites creates space shortages. As India being developing country is witnessing boom in construction, crucial natural resources are exploiting at very high rates. Official bans and restrictions to river mining leads to supply disruption of essential resources like sand, stones, and limestone. Thus, CD-W recycling for production of alternative construction materials is the best way of preserving primary raw resources. The stakeholder of large cities recycles CD-W knowing to the fact that resource potential of CD-W is nothing without recycling. But effective CD-W management is still hampered by several implementation and acceptance challenges in India. However, by following experiences of other countries and following proper CD-W processing, commercial recycling can be achieved.

2. OBJECTIVE OF THE STUDY

The aim of the dissertation is to identify the feasible utilization of specifically produced RF and RCP having grain size less than 4.75 mm as replacement of natural sand and cement, in concrete and mortar with reference to standards. To achieve the aim, the study was classed in three stages:

Stage I - Characterization of (RF) in terms of physical, chemical, mineralogical and microscopic properties.

Stage II - Feasibility of RF in mortar. (a) Investigating properties mortar containing different replacements percentages of sand and cement with CRCA and RCP, respectively. (b) Investigating effect of acid attack on properties of mortar containing RF.

Stage III - Feasibility of RF in concrete. (a) Investigating the properties of concrete containing RF as replacement of NFA at variable slump. (b) Investigating properties of concrete containing RF and CRCA as replacement of NFA at variable constant slump.

3. LITERATURE REVIEW

CD-W generation and its management policies

Global generation of CD-W has reached around 3 billion tons per annum, which is constantly increasing (Akhtar and Sarmah, 2018). CD-W reduction and its management through legislation and awareness is a global concern that will save environment. Thus, the worldwide information available on CD-W generation, existing legislation, and policies for CD-W dumping and recycling is given below. The comprehensiveness associated with CD-W varies from country to country, thus summarized information about important countries are discussed in the following survey:

in India Construction industry accounts for 10% of GDP of India, which is growing at a rate of 10% per annum as compared to 5.5% per annum of world normal. Currently, the CD-W generation of India is 530 million tons, which is second largest in the world. It is expected that built-up area will increase up to 104 billion square feet by 2030 (Centre for Science and Environment, 2014). Increase in construction activities will add up for CD-W generation likewise. CD-W occupies 30% among total generated municipal solid waste, which is estimated to be increasing 14.5 million tons/ year (Ashokan et al. 2007).

As per TIFAC (Technology Information, Forecasting and Assessment Council), construction industry produces 12-15 million tons waste annually. Among brick, masonry, soil, sand, gravels, metals, wood, bitumen and other wastes obtained from CD-W, Concrete comprises of 23% of total waste generated. The composition of CD-W as per TIFAC is

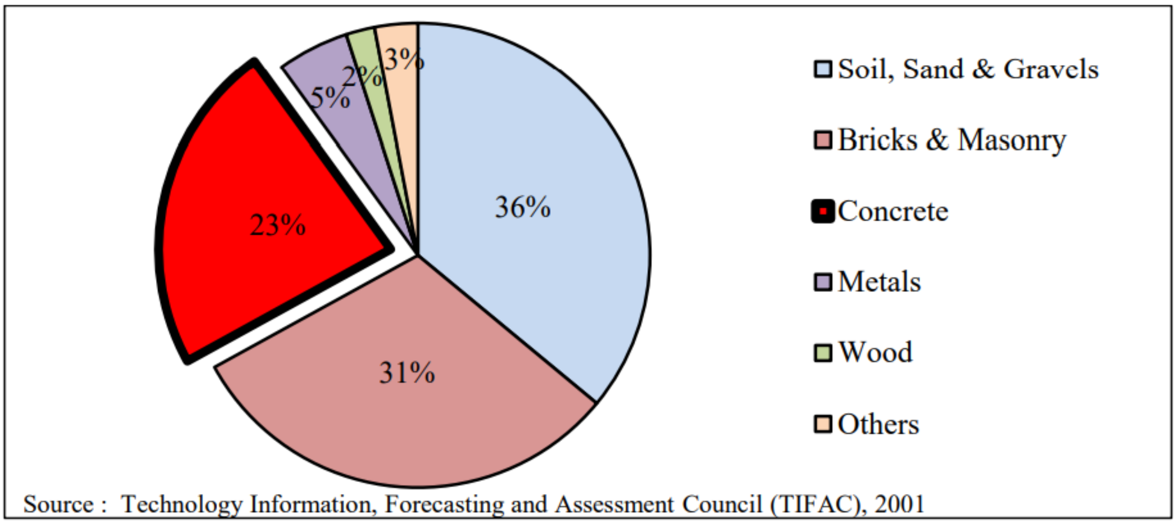


Figure.2.1. Typical composition of CD-W in India

Australia is the highest CD-W generating country in the New South Wales region, followed by Queensland and Victoria. Survey conducted on waste production and dumping reported recycling of 55% CD-W (Hyder Consulting, 2011). The states and territories of Australia handles waste management system rather than central body (Australian Government, 2012). Capital territories of Australia recycle 81% CD-W as compared to 71% of CD-W in South Australia. 72.3% of CD-W comprises of concrete, bricks, asphalt, etc., among which 66% of waste is recycled. However, Australian states are committed to recycle 70% under "Towards Zero Waste Strategy". Victoria targeted 80% material recovery from CD-W under Zero Waste SA, 2004 (Hyder Consulting, 2011). Australia also adopted waste reuse and recycling strategies by imposing landfill levy on waste disposal like New Zealand. Formerly, $42 to $102 was charged as fine for waste disposal, which was constantly increasing at a rate of $10 per year up to 2016, until the cost revision by Australian Government. However, the outcomes of recent actions are yet to be realized and further development plans must be planned accordingly.

In 2013, Rodrigues et al. carried out a survey on CD-W recycling facilities of Portuguese and found that majority of FRCA is produced using single stage crushing, while only few facilities uses secondary crushing processes.

In 2017, Ghanbari et al. reported use of several stages of crushing available in typical aggregate recycling plant. Firstly, the CD-W delivered in the facility is weighed and the one capable of being recycled is separated, stockpiled and conveyed to feed crusher. Later, the crushed material is passed from set of screens to segregate unwanted residues. The FRCA thus obtained may or may not be washed as per the requirement and stockpiled for further use In 2012, Florea and Brouwers separately prepared FRCA using conventional jaw crusher and prototype smart crusher. They observed particle size distribution (PSD) of FRCA, similar to that of NFA, when prepared using latter method. The prototype separated the FRCA particles in two ranges, one between 4.75 mm to 0.5 mm and second below 0.5 mm. The particles sizing below 0.5 mm were used in cement replacement by the author.

In 2015, Martinez et al. procured three types of sand from concrete recycling, mixed recycling and ceramic recycling, and used it in mortar of 1:3 and 1:4 proportion, simultaneously. The water absorption of concrete recycled sand, mixed recycled sand and ceramic recycled sand was 7.48%, 6.88% and 6.12%, respectively. The mortar with 50%, 75% and 100% replacement of natural sand with all three types of sand individually were prepared using water-cement ratio ranging from 0.57-0.89 and targeted consistency of 175±10mm. The mechanical strength of all the mortars was found poorer than the controlled mortar but were complying under the established standards.

In 2015, Fan et al. obtained FRCA1 and FRCA2 from two types of crushing methods and replaced it against 25%, 50% and 100% of NFA in 1:2 cement-sand mortar at two different water-cement ratios of 0.35 and 0.5, simultaneously. The water absorption percentage of NFA, FRCA1 and FRCA2 were 2.9%, 3.3% and 3.1%, respectively. The flow, density, compressive strength and ultra-sonic pulse velocities of mortar was found to be decreasing with the increase in FRCA percentages.

In 2018, Evangelista et al. used ceramic waste for preparation of fine recycled aggregates and replaced it with 0%, 20%, 30%, 50% and 100% of natural fine aggregate in 1:3 cement mortar. The water absorption of NFA was found to be 0.70%, whereas the water absorption of ceramic waste was 8.90%. They used 0.55% water-cement ratio for maintaining flow of 270±10mm. The replacement up to 30% showed no considerably lower results and was within the standards, while replacement up to 100% was not possible due to increased water demand.

In 2020, Goncalves et al. replaced 50% and 100% of NFA in 1:3 cement mortars with FRCA secured from crushing of C30 and C37 concrete in laboratory. The water absorption percentage of FRCA was 31 times more than that of NFA. They targeted consistency of 200± 15 mm by varying water-cement ratio from 0.5 to 1.28 and monitored more porous and less strength resistant micro-structure of FRCA mortar.

4. METHODS AND RESULTS

RF for the study was procured using specific method of crushing followed by sieving and segregation for definite utilization as NFA and cement alternative in concrete and mortar. RF derived from CD-W is divided in two materials, depending up on the particle size and its utility. Crushed recycled coarse aggregate (CRCA) was coarser portion of RF having particle size ranging between 4.75 mm to 150 µm; and recycled cement powder (RCP) was finer portion having particle size less than 150 µm. It was assumed that CRCA and RCP can individually meet requirements of sand and cement, respectively. However, study with RF, with or without RCP as replacement of sand is also executed to understand the role of RCP in imparting strength to concrete. The procurement process of RF is given in Figure. 3.1. The RF, CRCA and RCP to be utilized in the current research was produced as follows:

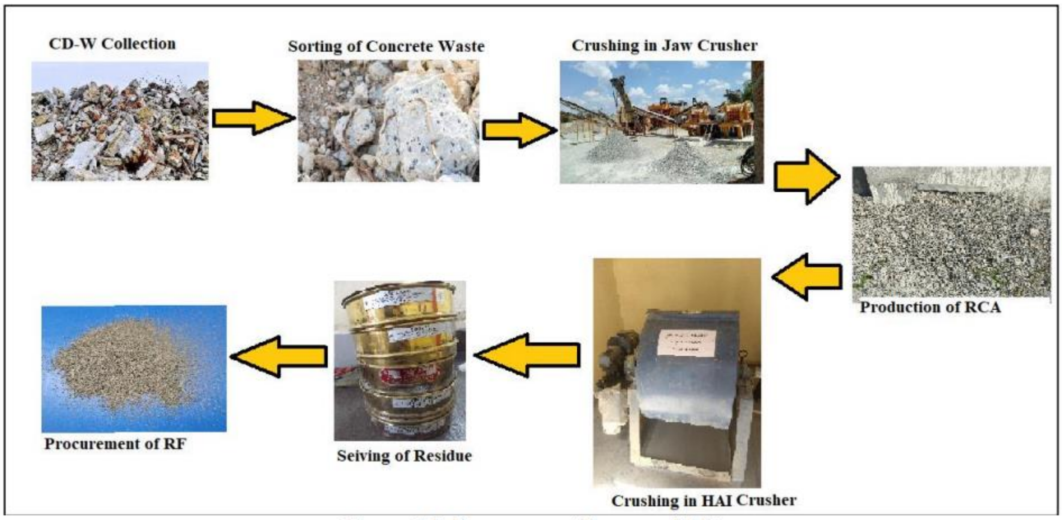


Figure.3.1. Procurement Process of RF

4.1 Selection of Raw Material

Concrete waste from demolished framed structure was used for CD-W procurement. The source of CD-W was kept same throughout the study to avoid the variation in results that may be caused due to change of source or compositional material. The CD-W is usually of composite nature, for example, brick waste, masonry waste, wooden waste, ceramic waste, concrete waste, etc. Here for the current research, only the concrete was considered for extraction of RF.

4.2 Re-sizing/ Crushing

The concrete was crushed in two stages for production of RF. The first stage crushing was to separately obtain recycled coarse aggregate (RCA) and other constituting material. Whereas the purpose of second stage crushing was to reduce size of RCA to produce RF. The various stages involved in crushing are as follows:

a. Stage-1: Waste Concrete to RCA in Jaw Mill Crusher Jaw mill crusher was used for extraction of RCA from concrete waste. The demolished concrete masses of nominal size 100 mm to 80 mm were reduced to aggregates of 20 mm or less. The concrete crushed remains with size less than 20 mm were considered as the aggregates of hardened mortar, thus excluded in further processing. The particles greater than 20 mm were sorted to ensure the presence of only RCA in it.

b. Stage-2: RCA to RF in Horizontal Axis Impact Crusher Horizontal axis impact (HAI) crusher or ball mill was used for size reduction of RCA to RF. The RCA of particle size ranging between 20 mm to 10 mm were crushed in ball mill with equivalent charge to obtain particles of size less than 4.75 mm. Crushing of RCA in ball mall not only reduces the size of grains but also separate the adhered mortar from the aggregates.

MIXING, CASTING AND CURING OF MORTAR SPECIMENS

Preparation of mortar mix has been done by manual gauging of all the ingredients in proportioned quantities on a thick cast iron table top using trowels. The amount of water varied as per the type of mortar specimens for different tests. For cubical mortar specimens to test water absorption, compressive strength, change in mass, and rate of water evaporation, the calculation of water required for preparing mortar was calculated as per BIS:4031(Part-6)-1988 and given in Equation 3.1. Whereas the required water for preparation of briquettes specimens to test the split tensile strength of mortar, was as per CRD-C 260-01, 2001 and was calculated with Equation 3.2.

$Water\ required\ for\ mortar\ cubes = (/ 4 + 3) \times W$

$$Water\ required\ for\ mortar\ briquettes = \left[\frac{2}{3}\left(\frac{P}{(n+1)}\right) + K\right] \times W \quad \text{...(Eq. 3.2)}$$

Where, P = Percentage of water required to produce normal consistency

n = No. of parts of sand to one part of cement by weight, which is 3 in this case

K = 6.5, constant for standard sand

W = Combined weight of cement and sand.

The replacement of 20%, 40%, 60%, 80% and 100% NFA was made with RF. Concrete with abovementioned replacements were designated as R0, R20, R40, R60 R80 and R100. The concrete with constant slump of 150 mm was prepared for the experiment. Higher workability was targeted in order to suffice the requirements of almost all kind of constructions. Thus, w/c ratio of 0.44 with all the constituent ingredients except NFA was maintained constant throughout the study, to observe the effect of constant water content in concrete with variable RF.

Mix Design

The concrete mix was prepared as per the guidelines of BIS:10262-2019. Concrete mix contained OPC-53 cement, silica fume, natural coarse aggregate (NCA), natural fine aggregate (NFA), recycled fines (RF), copper slag (CS), water and superplasticizer. The specifications of materials used in the study are as discussed in Chapter-3. The fine aggregates i.e., NFA, RF and CS were sieved to maintain gradation of zone-II, as per BIS:383-2016. Figure.5.1 shows the PSD of fine aggregates used in current study.

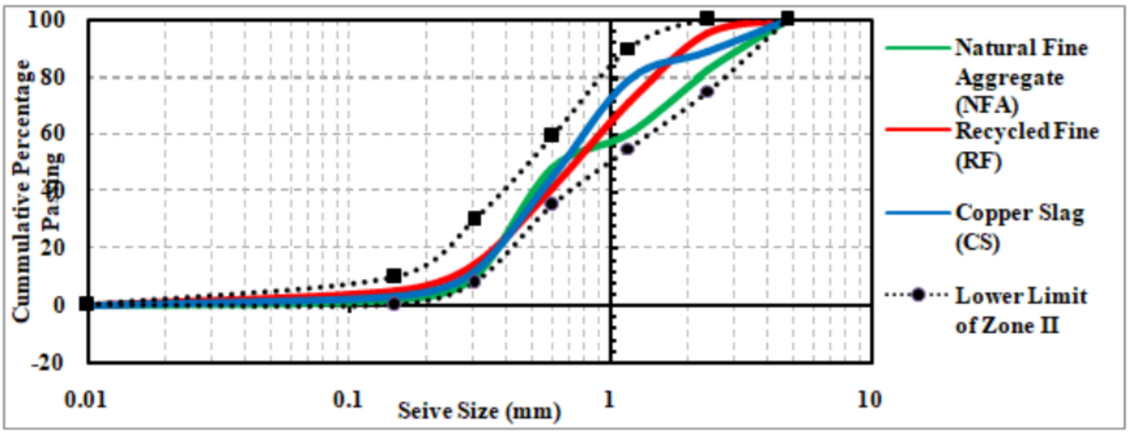


Figure.5.1. PSD for fine aggregates

The composition of concrete mix design is given in Table.5.1 and that of fine aggregate in Table.5.2 along with the corresponding slump values observed.

Table.5.1. Concrete mix proportions

Material	Quantity (kg/m³)
Cement	450
Water	200
NCA	864
Super-plastizier	9
Silica Fume	45

From Table.5.2, the concrete mixes above 60% replacement of NFA with RF have produced dry mixes. Also, as per BIS: 456-2000, the minimum required slump for medium degree of workability is 70 mm. Thus, non-water absorbing material, copper slag was incorporated as 5%, 10%, 15% and 20% of RF in replacements above 60% NFA to improve the workability. Table.5.3 shows the composition of concrete mixes with copper slag along with the corresponding slump values.

Table.5.2. Composition of fine aggregate in concrete mixes

Concrete Sample	R_0	R_{20}	R_{40}	R_{60}	R_{80}*	R_{100}*
NFA (kg/m³)	**662**	**530**	**397**	**265**	**132**	**-**
RF (kg/m³)	**-**	**132**	**265**	**397**	**530**	**662**
Slump (mm)	**150**	**135**	**103**	**75**	**-**	**-**

* *Dry mix with no slump value*

Effect of RF on Properties of Concrete

The test for workability on fresh concrete, and water absorption and compressive strength on hardened concrete was conducted on concrete specimens of variable RF content. Also, the microscopic analysis of hardened concrete was done using SEM technique for better understanding of behavior of RF in concrete. The results of tests conducted are discussed below:

a. workability Test

The reference concrete mix was designed to target 150 mm slump value with no water addition in later stages of replacement. Higher slump for reference mix was decided in order to compensate the increased water demands of RF on replacements. Evidently, high water absorption of RF has reduced the workability of concrete considerably with increasing RF percentages. In fact, concrete above 80% sand replacement was so dry that it could not be molded in frames. Thus, copper slag that typically has very low or negligible water absorption was introduced in the concrete in different percentages to compensate raised water demands. The slump values obtained by different concrete mix having variable RF and CS composition are given in Figure.5.2.

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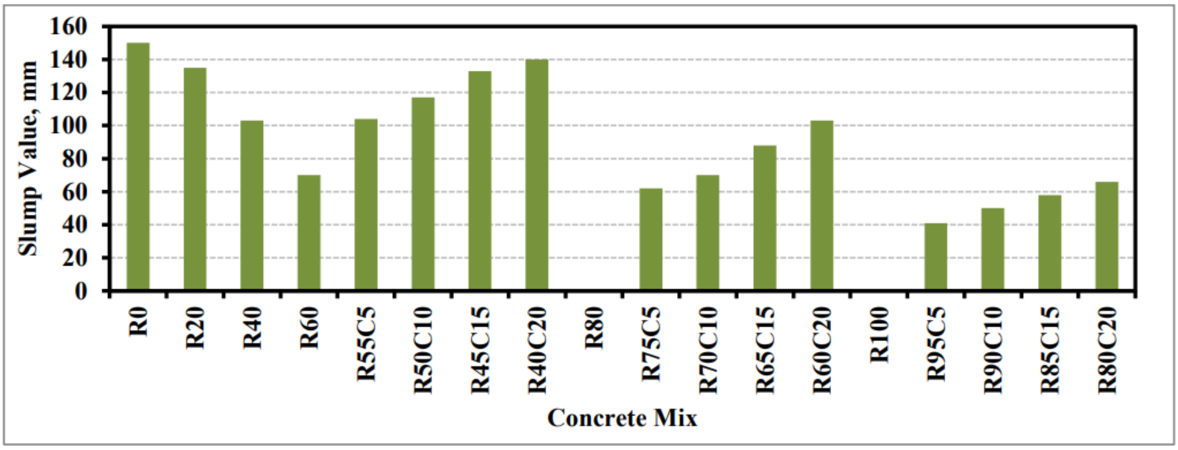

Figure.5.2. Workability of fresh concrete mixes with variable composition

Figure.5.2. also illustrates that increasing RF content in concrete is reducing the slump that is why, at 80% and 100% RF, the slump value is zero. Addition of CS to concrete mixes with low workability has improved the slump.

However, the percentage of CS was limited to 20%, in order to maximize the RF utilization and to maintain the slump above the minimum required slump value as given in BIS: 456-2000. b. Compressive Strength The concrete cubes were tested on 7th and 28th day of curing to determine the compressive strength. The results of 7th day and 28th day compressive strength are given in Figure.5.3. It can be observed form comparing Figure.5.2 and Figure.5.3, that despite highest workability of controlled concrete mix with all natural ingredients (R0), its compressive strength is found be least among all the mixes with varying percentages of RF, or in combination with RF and CS. Figure.5.4 shows the percentage variation in compressive strength of various concrete from that of reference concrete, R0, on 7th and 28th day. Figure.5.4 shows that all the concrete mixes with variable quantity of NFA, RF and CS has given higher compressive strength than the compressive strength of R0 on both the ages. Maximum 19.27% of increase in 7th day compressive strength was attained at R60C20 concrete as per Figure.5.4, which justifies early strength gain due to RF, suggesting early shuttering removal and thereby providing economy and speed to construction.

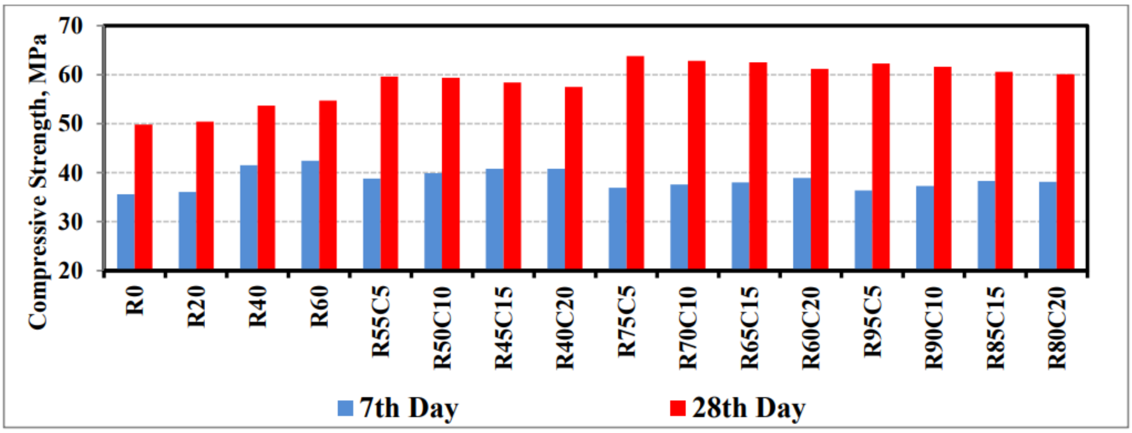

Figure.5.3. Compressive strength of concrete with variable composition on 7th and 28th day

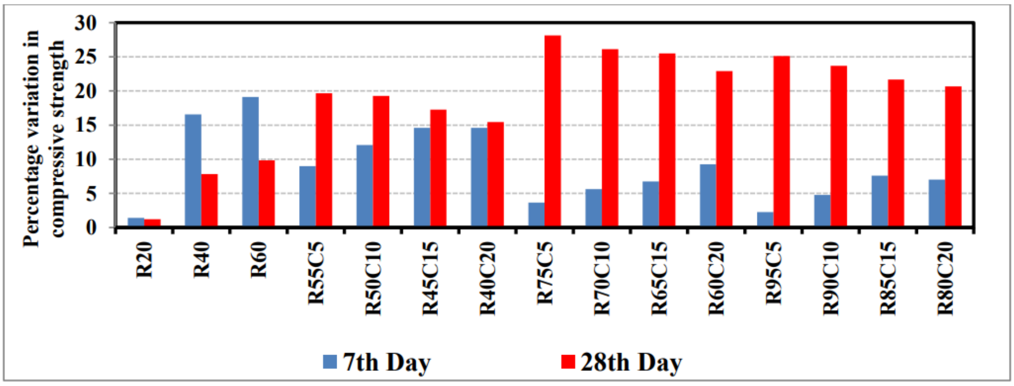

Figure.5.4. Percentage variation in compressive strength of concrete with variable composition

Whereas, from Figure.5.4, R75C5 saved 80% NFA and registered highest 28th day compressive strength which is 28.11% more than that of reference mix (R0). However, 100% NFA can also be saved with significant hike in compressive strength with proper control and vibrations for superior compaction. Cutting back 100% of natural sand with RF without strength compromise is an incomparable achievement that will open many corridors towards sustainable development. The physical properties of RF formed by attrition crushing provides extra bonding surfaces for binder adheration in concrete and better aptness in resisting compressive loads which increased compressive strength of concrete. R95C5 concrete mix with 25% increase in compressive strength and little compromise with slump (41 mm) have registered highest saving in NFA with RF and with least addition of CS. Unwashed RF was named as R-A and it constitutes CRCA and RCP both, and washed RF were named as R-B, where RCP were excluded. The effect of sulphate solution immersion was also observed on the strength and durability aspects of concrete made with R-A and R-B. Three classes of particle size ranges of fine aggregates were sieve separated as F1, F2 and F3 as given in Figure.5.8. F1, F2 and F3 were then kept separated in R-A and R-B and later recombined to form unitary, binary and ternary blends for determination of specific gravity, volume of voids and packing densities of each combination. The combinations were intended to obtain the blends with minimum, medium and maximum packing density, each for R-A and R-B, so that the study on each selected set of fines can be performed to evaluate the variations of their respective packing density on properties of concrete. Each combination of fines was provided with proper vibration and tamping for 2 minutes to evaluate the physical properties.

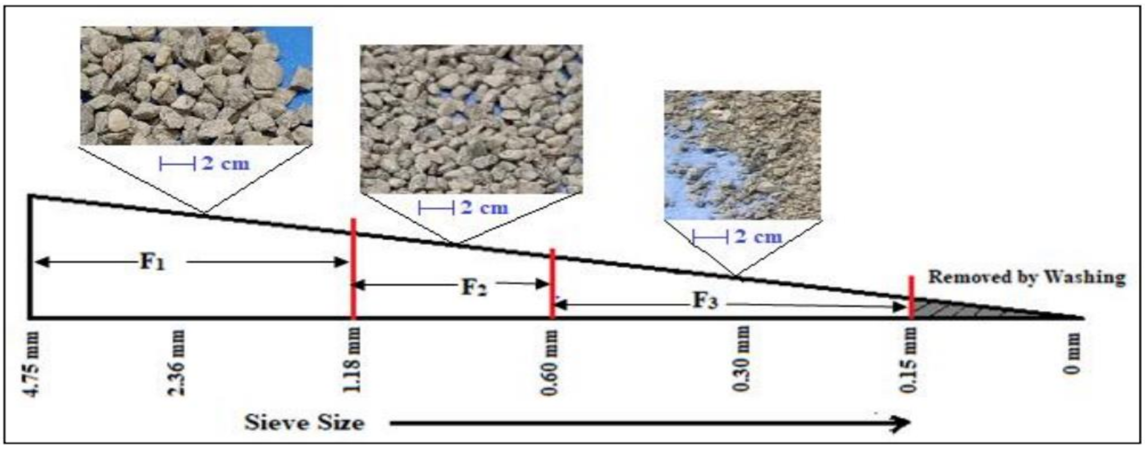

Figure.5.8. Separation of fine aggregates into three particle size ranges

Determination of specific gravity, volume of voids, bulk density and density of grains for fine aggregate combinations were done as per BIS:2386:3-1997. However, the packing density was determined by dividing density of grain to its bulk density as per ASTM C-29-09-2009. The physical properties of each blend of R-A and R-B are given in Table.5.4 and Table.5.5, respectively. Based on the packing densities of R-A and R-B samples as marked in Table.5.4 and Table.5.4, R-A combinations with minimum, moderate, and maximum packing densities were named as R-Amin, R-Amod and R-Amax, respectively. Similarly, R-B combinations of minimum, moderate and maximum packing densities were named as R-Bmin, R-Bmod and R-Bmax, respectively.

INTRODUCTION TO SUSTAINABILITY IN CONSTRUCTION INDUSTRY

Construction industry is massive, and it impacts almost all the existing industries around the world. About 6% of GDP of any country depends on this industry, and its an ever-growing industry as urbanization and infrastructural requirements are constant. Approximately 1/3rd of the total waste generated in the world is CD-W, which contributes 11% on an average to the total greenhouse gases produced worldwide. The current requirements of constructions cannot be considered sustainable and thus they are compromising the environment for the sake of development. Therefore, sustainability analysis of two major building materials, concrete and mortar becomes vital for construction industry. The sustainability in construction can be practiced by considering sustainable materials and by designing building for re-purposing. Its induction in construction industry can benefit in terms of cost reduction, increased productivity, waste minimization, better use of materials, environmental protection, better quality of life, emergence of new material and generates opportunity for experimentation.

There are three pillars of sustainability i.e., energy efficiency, environment, and society. Out of which environment is considered to be the most important in case of concrete and mortar. However, no universal approach can exactly evaluate the amount of energy a building material produces or utilizes during its lifetime. Evaluation of embodied energy (EE), embodied carbon (EC) and operational energy (OE) are the three important energies to be considered for environmental sustainability of building.

ENERGIES IN SUSTAINABILITY ANALYSIS EE

is the total required energy by all the associated processes involved in extraction, processing, manufacturing, transportation and delivery of material. EC is the amount of carbon dioxide or other greenhouse gases produced during manufacturing and service period of material. OE is the energy consumed by a building throughout its lifetime, such as energy utilized by lighting, heating, cooling, ventilating systems, etc. Therefore, EE and EC are the energy demands of integrated material, whereas OE is the functional energy requirement of the whole structure.

OE can be suitably controlled with proper building planning as regulated by current building policies. As the OE reduces, EE and CO2eq gain a significant importance for evaluation of lifetime carbon footprint of building (Vukotic et al., 2010). OE of domestic building are 1/10th time of its EE, whereas for commercial building, the OE can be as low as 1/30th time of EE (Hammond and Jones, 2008). Thus, the energy used in construction is of great importance that adds up to the assortment of building material and EE and EC of material are the important parameters for future saving decision making while construction planning (Wyatt, 2011). A case study by Hammond et al., 2008 showed that concrete contributes around 35% EE and 55% EC among all major building material, respectively.

The total amount of EE and EC of concrete is calculated by adding together EE and EC of all the materials used in its production weight-wise in 1 m3 of volume. Table.6.1 shows the values of EE and EC as given by various authors in previous literature. Where, EE was measured as MJ/kg and EC was measured as equivalent carbon dioxide emission (CO2eq) per kilogram of material.

Table.6.1. EE and EC of building materials used for concrete and mortar production

S.No.	Material	EE (MJ/kg)	EC (CO_2eq/kg)
1	Ordinary Portland Cement (OPC)	4.800	0.9300
2	Pozzolana Portland Cement (PPC)	3.080	0.6100
3	Natural Fine Aggregate (NFA) / Indian Standard Sand (ISS)	0.081	0.0023
4	Recycled Fines (RF) / Recycled Cement Powder (RCP) / Crushed Recycled Coarse Aggregate (CRCA)	0.046	0.0012
5	Natural Coarse Aggregate (NCA)	0.083	0.0048
6	Silica Fumes (SF)	0.036	0.0140
7	Fly-ash	3.090	0.3450
8	Super-plasticizer (SP)	11.50	0.6000
9	Water	0.200	0.0008

The EE and EC of copper slag (CS) was considered to be zero despite 9.121 MJ/kg of EE and 1.47236 CO2eq/kg of EC. As technically, high EE and EC of CS is due to the process of extracting refined copper metal by smelting process and as CS is an involuntary by-product of copper industry, does not have EE and EC of its own. However, CS utilization increases the 110 utilized energies of concrete, but being used as a waste in concrete it does not imposes any harmful effects on environment. In fact, CS in concrete is a better way of dumping it harmlessly as a promising quality enhancing material (Mithun and Narasimhan, 2016).

5. CONCLUSION:

The experiments on mortar for determination of CRCA and RCP utility in replacement of fine aggregate and cement, respectively and utility of RF in various mortar mixes has given the following conclusions:

- Higher water absorption of CRCA, RCP and RF particles induces higher water requirement in mortar mixes to maintain the same flow as that of NFA or ISS reference mortars. However, the raised water demand can be compensated with addition of super-plasticizer.
- The initial and final setting time of mortar raises slightly with addition of fine aggregate alternatives derived from RF. Though the setting times are well within the limits given in IS 1489 (Part-1): 2015, which is minimum of 30 min for initial setting time and maximum of 600 min (10 hours) for final setting time.The density of mortar prepared with RF reduces significantly with introduction of RF in place of NFA, due to the porous and light weightiness of RF grains.
- Early strength (on 7th day of curing) of mortar having RF is higher than the reference concrete, which suggests early formwork removal. Thus, saving cost and time.
- The strength of 1:3 reference cement-NFA or cement-ISS mortars was obtained to be similar with MR-b (1:3.5 cement-RF mortar) and C0S50 (5% cement replaced with RCP and 50% fine aggregate

replaced with CRCA), respectively.
- However, the strength of mortar having RF and its derivatives is lower to that of reference mortars, but well under the minimum required strength given in IS2250,1981, as per which the 1:3 mortar mix prepared with cement as binding material must have at least 7.5 N/mm2 of compressive strength at an age of 28th day of curing.
- Immersion of mortar having RF does not caused as significant losses as observed in reference mortar. Due to higher acid resistance properties of RF, the deterioration observed in RF mortars were lesser.
- RF, CRCA and cement can be used in mortars to have sustainability in construction. RF is capable for 100% utilization in mortar, while a significant saving in cement can also be achieved. Extra water, super-plasticizer or some material with less water absorbing characteristics has to be incorporated in combination with RF in concrete, so that the lowering of slump due to RF inclusion can be compensated.
- Due to rough and porous texture, the cement paste requirements of RF in concrete are high, but the strength it provides to the concrete is commendable. Micro-structural analysis on concrete shows that concrete with RF has more hydrated cement paste than the concrete having NFA.
- Copper slag (CS) can be used as a raised water compensating material along with RF in concrete, but the formation of weak ITZ around the CS particles, limits its utilization.
- CRCA resists the load by friction action between its angular and rough textures particles. However, the increase in cement paste requirements can also be lowered significantly by proper packing of concrete matrix.
- R-B (washed RF) performs well for compressive strength and mass loss under the immersion of specimens in sulphate solutions. However, the loss of mass was observed maximum in HNO3 solution followed by HCl and H2SO4.
- RF raises water demand in concrete and mortars, which can affect the strength adversely. However, the damage can be controlled with proper designing, gradation, mixing and by using suitable admixtures.
- The slump or the flow is a function of readily available free water in freshly mixed matrix, thus with RF, the slump reduces significantly. • The water retaining texture of RF allows the delayed setting of casted specimens.
- The mortars produced with RF have lower compressive strength than reference mortar. While in concrete with RF, compressive strength increases with the increasing percentages of RF. The variation in behavior of RF in the two materials is due to the availability of proper packing matrix in concrete than mortar required of RF to function well. As the load bearing capacity of RF concrete is higher due to the ability of RF to resist load with the friction action from its surrounding particles.
- RF supplements considerably as cement alternative to an extent of up to 20%, which implies that the cement utilization can be lowered and thus the associated harms to environment and human health can be reduced.

SCOPE OF FUTURE ENHANCEMENTS

In the future, the present work can be used as a benchmark in the revolutionary initiative of using RF obtained from CD-W as fine aggregate in concrete and mortar. However, following enhancements can be researched in future for betterment of technology:

- The material with the least water absorbing characteristics can be used along with RF in future studies, so that the major concern of high-water absorption by RF grains encountered in concrete and mortar mixing can be resolved.
- Techniques for CRCA development can be researched, that will reduce its water absorption and enhance its surface for better inter-particle packing.
- Further RCP extraction techniques from CD-W can be found, so that more desirable properties can be retained. • More set of CRCA and RCP are suggested, for optimized results in terms of mechanical strength and durability aspect.

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