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Preparation of Sustainable Concrete with Reduced Carbon Foot Print Using Recycled Aggregate, Fly Ash and Crumb Rubber

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KEYWORDS

cement, fly ash, crumb rubber, recycled aggregate, recycled aggregate concrete, CO_2 emissions, carbon credits.

ABSTRACT:
Concrete plays a vital role in construction, and is the second most used synthetic substance in the world. The enormous development of constructional activities lead to the generation of demolished and construction waste and it is one of the major components of waste generation. These generated materials are dumped on the land affecting the fertility of the soil. For the production of concrete 70% to 75% of aggregates are required. Out of this, coarse aggregate comprises 60% to 67%. From an environmental point of view, production of one cubic meter of natural aggregate concrete (NCA) emits between 323 and 332 kgCO2e. To reduce these carbon emissions, recycled aggregate (RA) from generated demolished structural waste is used as alternative aggregate to produce the recycled aggregate concrete (RCA), fly ash and crumb rubber act as binding materials and replacement for the cement to enhance recycled aggregate concrete (RAC) performance. Properties such as compressive strength, splitting tensile strength of recycled aggregate concrete (RAC) are studied and compared to natural aggregate concrete (NAC), for four different levels 10%, 20%, 30%, and 40% of recycled aggregate (RA) at 7 days and 28 days of curing. Recycled aggregate concrete (RAC) has optimum mechanical properties at 30% recycled aggregate (RA) replacement and is suitable for load-bearing structures. Recycled aggregate concrete (RAC) with 40% replacement showed a decrease in optimum strength but enough to be used for non-load-bearing structures. Use of recycled aggregate (RA) and cementitious materials fly ash and crumb rubber in preparation of concrete can save 1.19 GT CO2e annually for India, allowing a gain of 11,52,320 carbon credits each year.

1. Introduction

Approximately 4% to 8% of the total global CO_2 emissions arise from concrete with the precise figure influenced by several factors. During COP27, climate experts advocated for the reduction of greenhouse gas (GHG) emissions from the construction sector, encompassing the concrete, iron, and steel industries. These industries collectively contribute to 27% of the world's carbon emissions. Concrete alone accounts for more than 7% of the world's carbon emissions. Cement, a primary constituent, significantly contributes to these emissions, impacting the environment, thereby exerting a considerable influence on the overall environmental impact of concrete. The cement industry stands as one of the top producers of carbon dioxide (CO_2), contributing to approximately 5% of global emissions. This emission is divided, with around 50% originating from the chemical processes involved and 40% from the combustion of fuels. Carbon emissions significantly contribute to the global warming potential (GWP) within the impact category, amounting to 323 and 332 kg CO2e for concrete materials containing natural aggregates (NA) and cement, respectively [1]. The atmospheric temperature (average air temperature) has increased by about 1.1 ℃ since 1880. But since 1975, most of this warming has happened due to greenhouses gas emissions, with temperatures rising at a pace of about 0.15 to 0.20℃ every ten years.

Concrete production is a significant contributor to greenhouse gas emissions, primarily leading to CO_2 emissions. [2]. Recycling of waste concrete is beneficial, a necessary from the viewpoint of environmental preservation and effective utilization of resources [3]. Fly ash is evaluated as an alternative low-carbon binder for the stabilization of recycled aggregate concrete (RAC) used as a road construction material. The substantial reduction in the

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environmental impact of replacing general Portland cement with alternative good binders such asfly ash, along with the economic advantages of utilization of fly ash in construction activitiesis to tackle the negative landfilling impacts and carbon footprint of stabilization activities [4]. Concrete can be made more sustainable by incorporating the following practices.

Use of Recycled materials: Concrete made with recycled materials such as fly ash, slag cement, and recycled aggregates reduces the demand for virgin materials.

Reducing cement content:

Cement production is a major contributor to greenhouse gas emissions. By reducing the amount of cement used in concrete, its environmental impact can be reduced. India produces 36.671 gigatons of structural concrete annually, for which 16.501 gigatons natural aggregate is required. The quarrying, extraction, and transportation of natural aggregate releases 8.1g CO_2e per kg. Total CO_2 emission comes to around 4.9503 gigatons CO_2 e per year. Any amount of substitution of natural aggregate by recycled aggregate (Fig. 1) without affecting the regular properties of structural concrete can reduce carbon foot print. The recycling of construction and demolition waste is imperative for discovering tailored engineering applications that leverage recycled aggregates [5,6]. Recycling of (C&D) waste is enhancing the recycling process, but also mitigates disposal issues, ultimately preserving valuable natural resources [7]. Utilizing waste concrete, which constitutes a significant portion of construction and demolition waste, is recognized as a renewable material, and embraced as a sustainable technology [8].

Fig. 1 Recycled aggregate

The carbonation rate is reduced in concrete mixes that incorporate a high volume of recycled coarse aggregate (RAC) [9]. To produce 36.671 gigatons of structural concrete, around 1.6456 gigatons of cement are needed, and it results in the production of 1.15192 gigatons CO_2e emissions. The sustainable usage of fly ash in large civil engineering projects will enable to the diversion of significant quantities of this waste materials from landfills [1]. (Arun Arul rajah, Alireza Mohammadi, 2016). CO_2 emission from the production of ordinary Portland cement is increasing sharply world wise.

To reduce the CO_2 emission caused by OPC, fly ash has been used as partial replacement to OPC [3]. Using crumb rubber as partial replacement for cement in concrete offers several potential benefits, including improved mechanical properties, enhanced durability, and reduces disposal of waste tires [10]. Replacing rubber waste in concrete can significantly reduce environmental contamination caused by the non-decomposable materials found in used tires. [11]. The utilization of cementitious materials like fly ash and crumb rubber as replacements for cement, while maintaining desired characteristics, offers the potential to decrease carbon emissions.

2. Objective

The objective of this work is to perform tests on different concrete materials to ensure compliance with the Indian Standard (IS) codes, and to evaluate the potential of replacing natural aggregate with recycled aggregate and partially substituting cement with fly ash and rubber crumb producing sustainable concrete with reduced carbon foot print.

3. Materials and methods

3.1 Cement

All concrete mixtures are made with Zuari OPC 53 Grade cement (Fig. 2) manufactured by grinding clinkers. OPC cement is versatile and suitable for various applications, including residential, commercial, and infrastructure projects. Its composition is a vital component in concrete and mortar blends.

Fig. 2 OPC Cement

3.2 Natural aggregate and Recycled aggregate

Two kinds of coarse aggregates namely natural aggregate (NA) (Fig. 3) and recycled aggregate (RA) are utilized to

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create structural concrete. Both aggregates are procured locally at Ananthapuramu.

Fig. 3 Natural aggregate

3.3 Fine aggregate

River sand from Anantapur is used as fine aggregate (Fig. 4) to create structural concrete.

Fig. 4 Fine aggregate

3.4 Fly ash

Fly ash is utilized for partial replacement of cement and is sourced from the AP GENCO ash pond (Fig. 5) located in Nelaturu, SPSR Nellore District, Andhra Pradesh, South India.

Fig. 5 Fly Ash (FA) pond in A.P GENCO (14.95246,78.05046)

3.5 Crumb rubber

Crumb rubber procured from Sree Venkata Srinivasa Industries, from Srikakulam, Andhra Pradesh as fine powder was utilized to partially substitute cement. The properties of crumb rubber as provided by the manufacturer shows that 83% is rubber and carbon black (Table 1)

Table 1 Characteristics of crumb rubber

Physical properties	
Size	Fine powder
Color	Black
Elongation (%)	420
Density (Kg/m³)	0.83
Chemical properties	
Rubber (%)	54
Carbon black (%)	29
Textile (%)	2
Sulphur (%)	1
Zinc (%)	1

3.6 Water

Ground water from bore wells of the college is used for both mixing and curing of the concrete (Fig. 6).

Fig. 6 Preparation of concrete mix with water

3.7 Tests on cement

3.7.1 Test in the filed

A field test usually refers to a variety of on-site tests carried out to evaluate the qualities and characteristics of cement in actual conditions.

3.7.2 Laboratory tests

Laboratory tests on cement evaluate its quality and characteristics, ensuring compliance with IS Standards for construction applications.

Setting time tests

The normal consistency of a cement paste determines the amount of water needed for the Vicat plunger to penetrate 5-7 mm from the bottom of the Vicat mould, crucial for determining initial and final setting times.

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Fineness of Cement

Finess of cement is essentially informing you of the size of the cement particles present in a particular cement sample.

Specific gravity of cement

The specific gravity of cement serves as a measure of its quality. Specific gravity of cement is determined using kerosene that does not react with cement.

3.8 Tests on fine aggregate

Particle size distribution

Particle size distribution is conducted to evaluate the particle size in an aggregate sample, and it is referred as gradation.

Specific gravity of fine aggregate

It is an important property that can be used to evaluate the consistency and quality of fine aggregate. The specific gravity of the material is usually measured using pycnometer as part of the quality control procedure.

3.9 Tests on coarse aggregate

Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles, The particle shape and surface texture influence the properties of freshly mixed concrete.

Elongation index

The elongation index is an experimental method tomeasure the length of the coarse aggregate, presence of more elongated particles disturbs the packing of the concrete.

Specific gravity and water absorption test

The specific gravity of aggregate serves as a measure of material quality. Lower specific gravity values typically indicate weaker characteristics, whereas higher specific gravity values suggest stronger characteristics in aggregates. Water absorption in aggregates or saturated aggregates enhances the strength of rocks. However, stones with higher water absorption rates are typically considered unsuitable.

Particle size analysis

Particle size analysis is a method used to determine the particle size distribution of coarse aggregates such as gravel and crushed stone to classify them into different size ranges as per IS sieves. This information is essential for designing concrete mixes and other construction materials.

3.10 Tests on fly ash

X-ray diffraction (XRD) Test

X-ray diffraction is a technique used to analyse the arrangement of atoms or molecules within a crystal structure. XRD involves shining X-rays onto a crystalline sample (Fig. 6) measuring the patterns of diffracted X-rays, that result helps to determine its crystal structure.

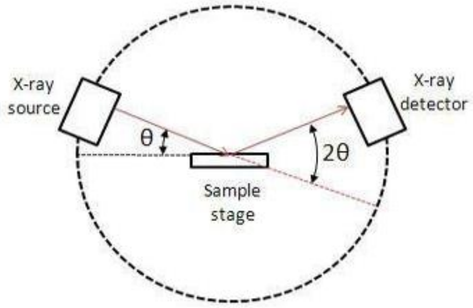

Fig. 6 XRD (X Ray diffraction)

Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS)

Scanning Electron Microscopy (SEM) (Fig. 7) is a method employed to produce high-resolution, three-dimensional images of a sample's surface, exposing its topography and structure in detail at an enlarged scale.

EDS (Energy-Dispersive X-ray Spectroscopy) is a method used to identify and quantify the elemental composition of a sample by measuring the characteristic X-rays emitted when the sample is exposed to electron bombardment. This technique aids in determining the presence of elements and their spatial distribution within the sample.

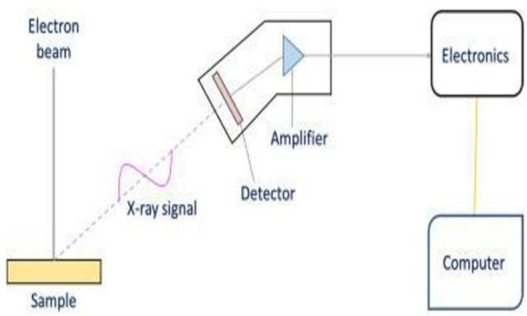

Fig. 7 SEM & EDS

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3 .11 Tests on hardened concrete

Compressive strength test

A compressive test procedure (Fig. 8) is a standardized method used to determine the compressive strength of materials, such as concrete, metal, or rock. Compressive strength refers to the ability of a material to withstand axial loads or forces pushing it together without undergoing permanent deformation or failure. This method is frequently employed in material testing to evaluate the quality and structural integrity of materials.

Fig. 8 Compressive Strength Test

Splitting tensile strength test

The splitting tensile strength procedure refers to the process of testing a material's ability to withstand tension or pulling forces before it breaks or undergoes deformation. This technique is frequently employed in material testing (Fig. 9) to evaluate the quality of the material of materials.

Fig. 9 Splitting tensile strength

3.12 Quantification of carbon emission

By integrating 30% recycled aggregate into India's structural concrete production, significant reductions in carbon emissions can be achieved. With an annual output of 36.671 gigatons of concrete, the nation currently consumes 16.501 gigatons of natural aggregate. By substituting 30% of natural aggregate with recycled aggregate, a substantial portion of natural aggregate can be saved, potentially cutting carbon dioxide emissions annually. Additionally, substituting 22% of the cement with alternative materials such as fly ash and crumb rubber further decreases CO_2 equivalent emissions.

3.13 Carbon credits

Carbon credits derived from natural aggregate are calculated by dividing the emissions from natural aggregate by a factor of 1000. For cement, the carbon credits are determined by dividing the emissions produced by cement by 1000.

4. Results and discussion

4.1 Experimental Test on Cement

The provided sample's normal consistency was found to be 29% of water required to mix cement. OPC typically has a consistency is limited to 26% and 33% according (Table 2). The initial setting time for the provided sample was 56 minutes, the maximum initial setting time for OPC grade 53 is limited to 60 minutes according to Indian Standards, the experimental value fell inside the upper bound (Table 2). The setting in the end period of the sample is 6 h 24 min; while the maximum final setting for OPC grade 53 is set to 6 hours according to IS Standards (Table 2).

According to IS Standards, the fineness of cement is limited to below 10%. The obtained value is less than 10% (Table 2). According to IS Standards, the specific gravity of cement is limited to 3.10 and 3.15, and the measured value is 3.12 (Table 2).

Table 2 Test results of Cement.

Tests	Experimental Results
Normal Consistency	29%
Initial setting time	56 min
Final setting time	6 h 24 min
Fineness of cement	4.93%
Specific gravity	3.12

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4.2 Experimental Test on Fine aggregate

The fineness modulus is recorded as 3.31. Based on the results, the sand meets the specifications of Zone-II. The measured fine aggregate's specific gravity is 2.583; the range of specific gravities for fineaggregate is limited to 2.5 to 3.0 according to Indian Standards.

Table 3 Test results of fine aggregate.

Tests	Experimental Results
Particle size distribution	3.31
Specific gravity	2.583

4.3 Experimental Test on Coarse aggregate

The flakiness index and elongation index of natural and recycled aggregates (RA and NA) are both capped under 30% (Table 4). The measured specific gravities of both natural and recycled aggregates are 2.627 and 2.607; the range of specific gravities of coarse aggregate is limited to 2.0 and 3.0 (Table 4). The water absorption of both natural aggregate and recycled aggregate is restricted to a value lower than 1% (Table 4).

Table 4 Test results of coarse aggregate

Test	Experimental results	
	NA	RA
Flakiness Index	7.65%	7.19%
Elongation Index	14.57%	12.83%
Specific gravity &	2.626	2.607
Water absorption	0.34%	0.43%
Particle size distribution	6.733	6.990

4.4 Experimental Test on Fly Ash

XRD

By analysing the positions and intensities of the peaks in the XRD (Fig. 10) graph drawn using 'Orient' software determines the crystal's lattice parameters like structure and face of the material, by comparing the experimental diffraction pattern with known patterns in databases allows the identification of the crystal structure and face of the material. The position of intensities & peaks concluded that the fly ash has a hexagonal face with the help of a Match Face Analysis Report.

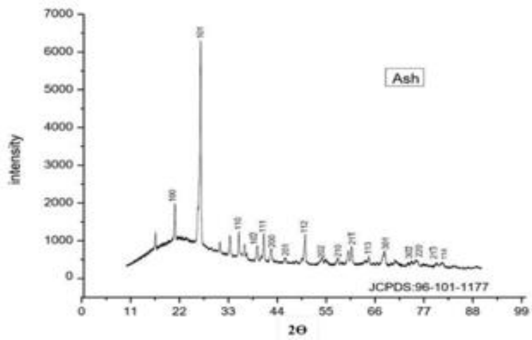

Fig. 10 Diffractogram

SEM and EDS

An image taken at 1 µm (Fig. 11), offers important information on the physical characteristics of fly ash particles. Average particle size of the fly ash particles after examination using Image J software is determined as 5.2 µm.

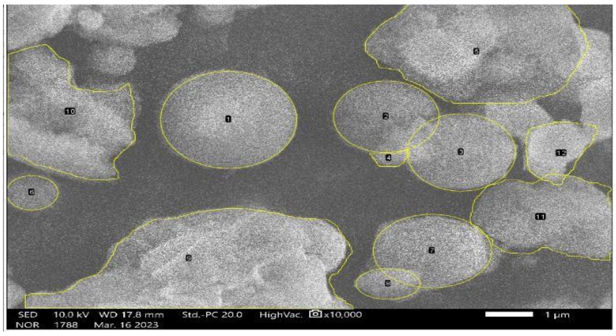

Fig. 11 Image analysis by SEM

Fly ash samples primarily consist of two main components: oxygen and silicon (Table 5). Both materials were evident on the particle surface, and cross-sections clearly revealed their thorough mixture throughout the fly ash particles. Additionally, calcium is the third most abundant element in the fly ash.

Table 5 Chemical composition of fly ash

Element	Weight %	Atomic %
Ca	15.3	23.2
O	43.33	49.31
Mg	2.91	2.18
Al	14.15	9.55
Si	24.31	15.76

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4.5 Experimental Tests on hardened concrete

Compressive strength test

For each mix of recycled aggregate concrete, the compressive strength is determined taking three specimens over a period of seven and twenty-eight days of curing (Table 6) and by subjecting to compressive strength test on a Universal Testing Machine (UTM).

Table 6 Compressive strength at 7 and 28 days

% RA replacement	7 days N/mm^2	28 days N/mm^2
0	17.831	30.834
10	18.501	32.370
20	19.032	31.629
30	19.226	.32.086
40	17.604	30.621

The graphical representations (Fig. 12, 13) show the optimum compressive strength at 30 % replacement of natural aggregate by recycled aggregate and substituting cement with 7% and 15% of crumb rubber and fly ash respectively for a period of 7 days and 28 days of curing.

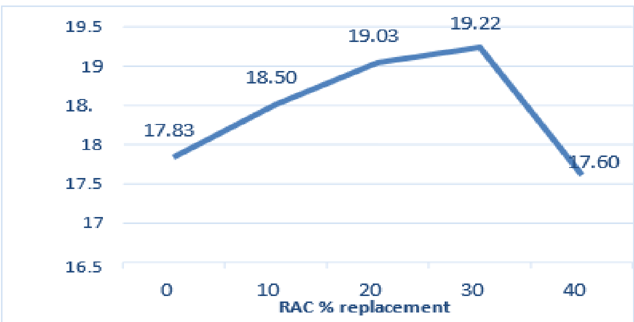

Fig. 12 Compressive strength at 7 days

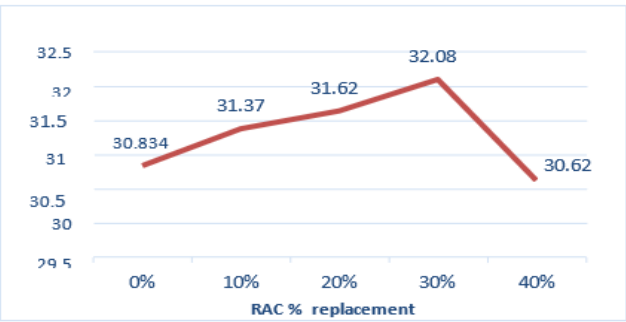

Fig. 13 Compressive strength at 28 days

Splitting tensile strength test

For each mix of recycled aggregate concrete splitting tensile strength is determined taking three specimens over a period of seven and twenty-eight days of curing (Table 7) and by subjecting to splitting tensile strength test on a Universal Testing Machine (UTM).

Table 7 Spltting tensile Strength at 7 and 28 days

% RA replacement	7 days N/mm^2	28 days N/mm^2
0	1.601	2.130
10	1.679	2.379
20	2.049	2.673
30	2.217	2.920
40	1.532	2.107

The graphical representations show the optimum splitting tensile strength at 30 % (Fig. 14, 15) replacement of natural aggregate by recycled aggregate and cement with 7% and 15% of crumb rubber (CR) and fly ash (FA) respectively for a period of 7 days and 28 days of curing.

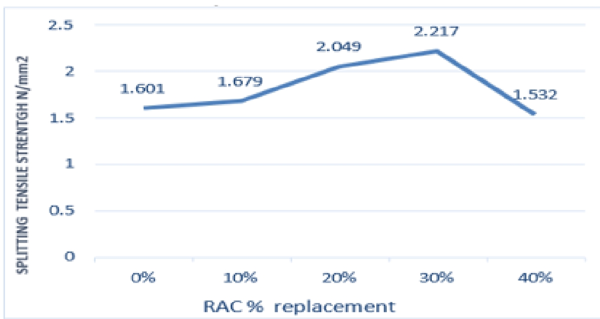

Fig. 14 Splitting tensile strength at 7 days

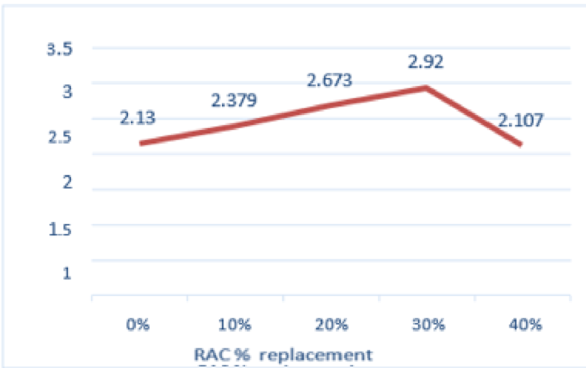

Fig. 15 Splitting tensile strength at 28 days

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5. Conclusion

All properties of concrete materials used for concrete making, meet Indian Standards (IS). Greater replacement ratio of recycled aggregate, the lesser strength developed in the recycled aggregate concrete (RAC). But at any instant, the strength of recycled aggregate concrete is higher than the strength of natural aggregate concrete (NAC) up to 30%. In the case of water absorption, the RAC exhibits higher water absorption values as compared to NAC. The presence of attached mortar on aggregates, leads to more water absorption nature in the concrete. A 30% replacement of natural aggregate (NA) in concrete does not lead to a significant strength reduction. This proportion can be considered optimal, given its positive influence on mechanical properties. Recycled aggregate concrete (RAC) with a 40% replacement rate of (RA) showed a decline in optimal strength, however, it maintained enough strength to be deemed suitable for non-load-bearing structures. By adopting replacement of 30% natural aggregate with recycled aggregate and 22% substitution of cement with crumb rubber and fly ash, India can gain up to 1152320 carbon credits annually. Integrating recycled aggregate, fly ash, and crumb rubber into construction practices contributes to environmental preservation and minimizes waste, mitigating carbon emissions and waste disposal problems.

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