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Evaluating the durability performance of concrete containing clastic sand and GGBS

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ABSTRACT

The manufacturing process of materials utilized in concrete production has environmental implications. The production of cement releases significant amounts of greenhouse gases, while the extraction of aggregates and sand poses challenges to the natural environment. To minimize the aforementioned challenges researchers are suggested to utilize industrial by-products as a partial alternative for these materials Fly ash, stone dust, GGBS, silica fume, and metakaolin are widely utilized alternatives to construction materials. The specific use of clastic sand as a partial substitute for fine aggregate has recently gained popularity . However, studies on the characteristics of concrete prepared using cementitious materials and clastic sand are very few. In this work, the effect of clastic sand with ground granulated blast furnace slag concrete is being investigated. The GGBS is added in place of cement from 0% to 45%. Further, clastic sand is added in different proportions in GGBS concrete. The electrical resistivity, water absorption, acid attack, and micro-structural studies are carried out on all mixes to know the durability properties. The results confirm that the addition of GGBS as a cementitious material enhances durability. The inclusion of 35% of GGBS as a substitute for cement is optimum for enhancing durability. Further, the inclusion of 35% GGBS as a cement substitute and 20% clastic sand shows a dense matrix and optimum results in enhancing durability. This is due to the pozzolanic activity of GGBS and clastic sand works as filler materials. This investigation suggests utilizing clastic sand along with GGBS as a cementitious material.

1. Introduction

Concrete is the most widely used material on the earth due to its desired strength and durability. The river sand is naturally utilized as a fine aggregate in the construction of concrete structures. The demand for natural sand is increasing day by day due to the rapid growth of infrastructural development. Every year, the need for sand in emerging nations grows; as a result, sand has been extracted between 32 to 50 billion tons globally. Sand mining is a global industry that has significant social and environmental repercussions, ultimately affecting freshwater ecosystems [1]. Furthermore, the quantity of sufficient natural sand near the construction site is getting depleted, and the price of the sand is growing [2]. The reduction of natural resources leads to the accumulation of industrial waste as aggregates in concrete [3]. Furthermore, one of the key difficulties confronting construction and other industries nowadays is the large output of industrial waste or byproducts [4]. As a result, there is a need to discover a sustainable material to replace some of the natural components included in concrete.

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Abbreviations:

SCM	Supplementary cementitious materials
GGBS	Ground Granulated Blast Furnace Slag
CLS	Clastic sand
OPC	Ordinary Portland Cement
XRD	X-ray diffraction
XRF	X-ray fluorescence
RCPT	Rapid Chloride Penetration Test
AAT	Acid attack test
WPT	Water permeability test
SAT	Sulphate attack test
CSH	*Calcium silicate hydrates*
CSAH	*Calcium silicate alumina hydrates*
IS	Indian code
ASTM	American Society for Testing and Materials

Greek symbols

µ	Particle size
G	Specific gravity

To diminish the number of natural aggregates needed in concrete, it is critical to employ industrial waste or byproducts in various ways. Many industrial waste products, such as bottom ash, marble dust, furnace slag, ceramic waste, limestone, quarry dust, copper slag, and recycled concrete aggregate, have been partially or completely mixed into concrete to replace fine aggregate as a sustainable resource [5], [6], [7][8]. In order to keep aggregates from stacking up later on, it is critical to investigate and find a variety of alternatives to natural sand. Recently, it has become more common to use clinker sand or sandstone waste as a partial alternative to fine aggregate [9], [10]. Sandstone is a clastic sedimentary rock composed of microscopic sand grains that are linked together by cementing materials such as clay, silica, or iron oxide. Sand particles are mostly feldspar and quartz. The state that produces the most sandstone in India is Rajasthan. More than 90% of the typical sandstone produced in India comes from there. It is located in the significant Vindhyan and Trans-Aravalli-Vindhyan sequence, which spans 34,000 square kilometers in the western desert plain and eastern Rajasthan [11][12]. Large-scale production generates a large amount of waste, which must be properly utilized. Researchers used clastic sand to make concrete more sustainable. However, there are few studies available on the performance of concrete including clastic sand as a substitute for river sand. It is necessary to investigate how well concrete works when clastic sand is used. Furthermore, regular Portland cement employed in construction proves to be an environmental threat, releasing significant volumes of greenhouse gases into the surrounding atmosphere [5], [13], [14]. This approach intends to maintain such benefits while lowering the significant economic and environmental costs by lowering the cement content. The strength and durability features of concrete mixes can be reduced with the use of cementitious components, which can also sometimes improve these characteristics. Increasingly used cement substitutes are silica fume and ground granulated blast furnace slag (GGBS) [15], [16], [17], [18]. The iron production sector produces waste products like GGBS. Enhancing the durability and bond between the particles is made possible by the physical and chemical features of GGBS [19], [20], [21]. This investigation aims to find the optimum dosages of clastic sand as a fine aggregate replacement along with GGBS as a cementitious material.

2. Materials and mix proportions

53-grade Ordinary Portland Cement [OPC], conforming to IS 269-2015 [22] was utilized. Specific gravity, a fundamental physical test, was conducted, yielding a specific gravity of 3.14 and a normal consistency of 31%, which falls within the acceptable limit. The selected fine aggregates adhere to the standards outlined in IS 383-2016 [23] fall under the category of zone II grade and have a specific gravity of 2.65. The coarse aggregate is assessed according to the IS 383-2016 standard [23], with a maximum aggregate size of 20mm (fineness modulus 7.17 and specific Gravity - 2.66). The GGBS used in this investigation was procured from a reputable manufacturer. Chemical analysis of the GGBS was conducted using the XRF technique, and the results are detailed in Table 1, showcasing its chemical properties.

Table 1. Chemical properties and characteristics of GGBS

Composition	Proportion (%)
SiO_2	31.65
Fe_2O_3	00.37
Al_2O_3	12.40
CaO	43.17
MgO	05.80
MnO	00.58
SO_3	00.37
Na_2O	00.91
K_2O	00.18
TiO_2	00.40
LOI	02.01
Fineness (%)	03.00
Avg particle size (µm)	12.00
Specific gravity	02.60

The properties of clastic sand are listed in Tables 2 and 3. In this research, the clastic sand was observed to fall within the sub-mature group and sub-arkose type. The grains exhibited moderate sorting, with a shape ranging from sub-angular to sub-rounded.

Table 2. Physical properties of clastic sand

Physical properties	Test value
Color	Red
Fineness modulus	2.80
Bulk density	1650 (kg/cum)
Water absorption	10.5
Specific gravity	2.56

Table 3. Chemical Properties of clastic sand

Chemical properties	Test value
SiO_2	94.68
Fe_2O_3	04.90
Al_2O_3	00.24
CaO	NIL
LOI	00.17

Table 4. Mix proportions (kg/m^3)

Mix Details	Cement	GGBS	Fine Aggregate	Clastic Sand	Coarse Aggregate	Superplasticizer	Water
CM	392.0	00.0	822.0	00.0	1077	0.75	156.8
G15	333.2	58.8	822.0	00.0	1077	0.75	156.8
G25	294.0	98.0	822.0	00.0	1077	0.75	156.8
G35	254.8	137.2	822.0	00.0	1077	0.75	156.8
G45	215.6	176.4	822.0	00.0	1077	0.75	156.8
G35CS10	254.8	137.2	739.8	82.2	1077	0.75	156.8
G35CS20	254.8	137.2	657.6	164.4	1077	0.75	156.8
G35CS30	254.8	137.2	575.4	246.6	1077	0.75	156.8
G35CS40	254.8	137.2	493.2	328.8	1077	0.75	156.8

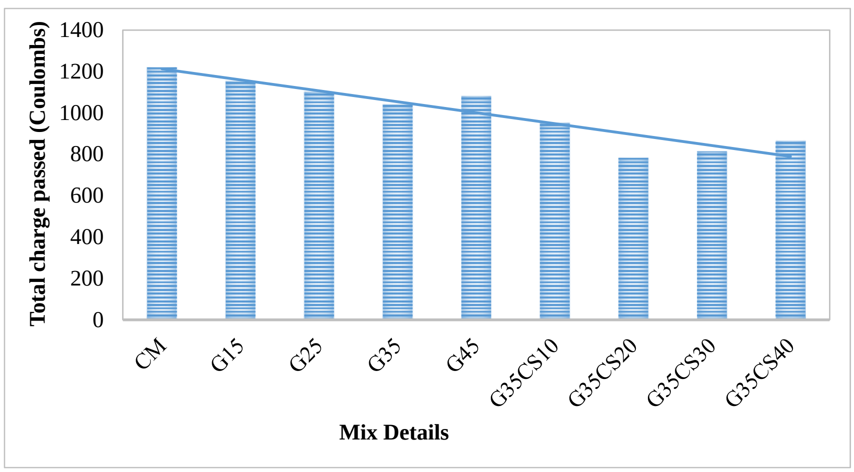

Figure 1. RCPT Test results of different mixes.

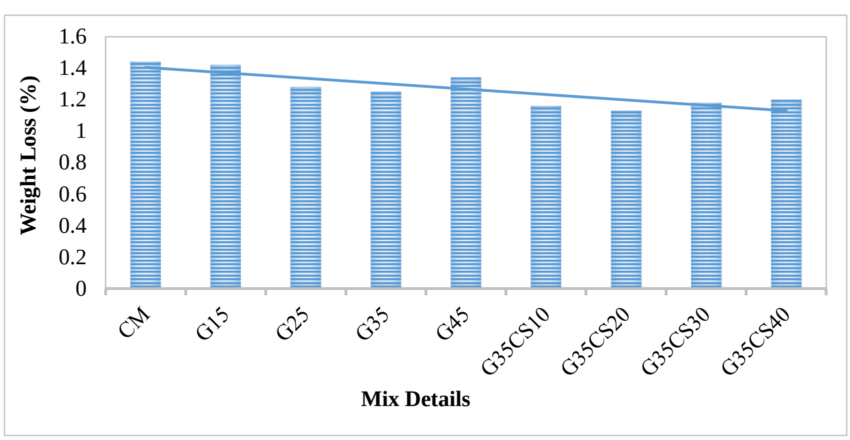

Figure 2. Acid attack test results

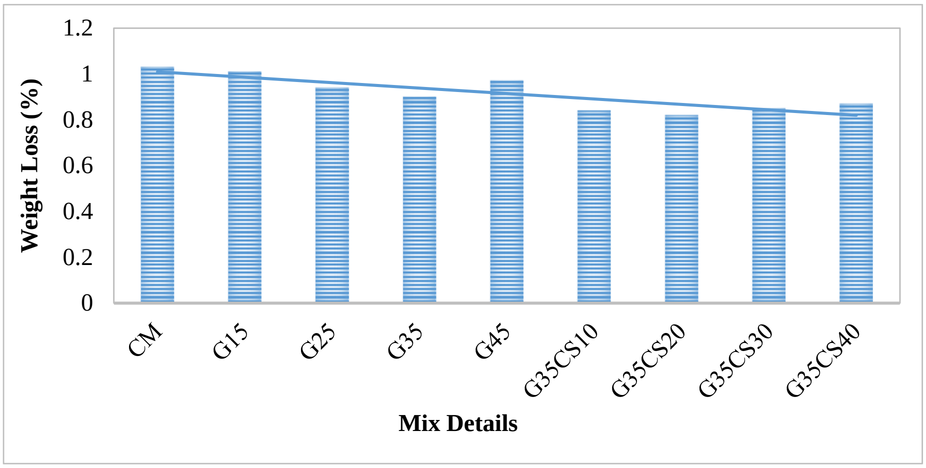

Figure 3. Sulphate attack test results

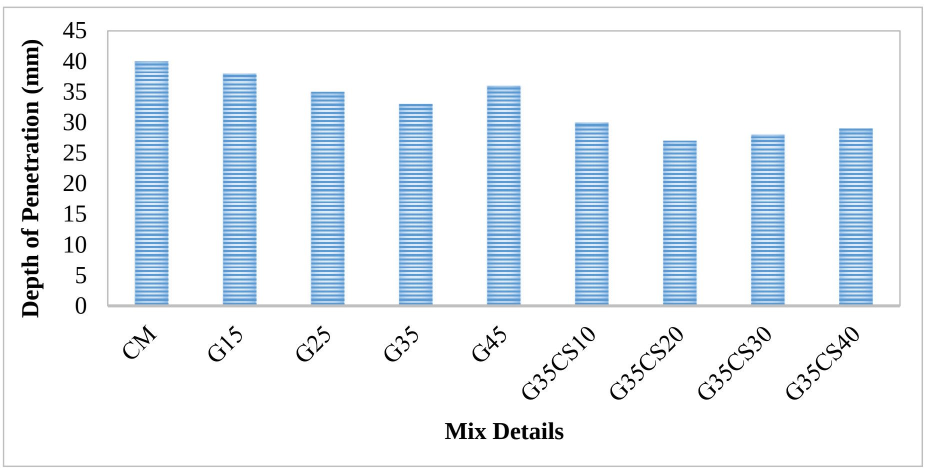

Figure 4. Water permeability test results.

A Polycarboxylate (PCE) based admixture was utilized. To ensure optimal workability and consistent slump values, a high-range water-reducing admixture based on polycarboxylate was employed. Throughout the study, standard tap water was utilized. PCE was kept constant throughout the research. Nine concrete mixtures were created using GGBS and clastic sand. These mixtures were divided into two groups.

In the first group, cement was partially substituted with GGBS at varying percentages of 15%, 25%, 35%, and 45%. In the second group, after determining the optimal quantity of GGBS, sand was replaced with clastic sand at percentages of 10%, 20%, 30%, and 40%. Table 4 provides an overview of the cement, GGBS, fine aggregate, clastic sand, coarse aggregate, water, and chemical admixtures used in each mixture

3. Results and discussion

3.1. Rapid chloride penetration test

The RCPT is an important test to assess the concrete quality against chloride ion penetration, which can lead to corrosion of reinforcement and deterioration of structures. According to ASTM C 1202 [24], the test was conducted on all mixes in triplicate for 28 days of water-cured samples in this investigation. As per ASTM 1202 the charge passed is between 1000 to 2000 then chloride ion penetration is low. Also, if it is between 100 to 1000 then the chloride ion penetration is very low. The test results of the current study are depicted in Fig.1. From Fig.1 it is observed that the addition of GGBS enhances the resistance to chloride ion penetration. This is because the accumulation of GGBS enhanced the hydration process, resulting in the generation of C-S-H and C-A-S-H [25]. Also, it further acts as a filler material minimizes the pores present in the concrete mix, and makes concrete denser. The inclusion of 35% of GGBS in place of cement is optimum for enhancing durability.

Further, the fine aggregate in this G35 mix has been replaced with clastic sand in different proportions. The addition of clastic sand to the G35 mix exhibits further resistance to chloride ion penetration. According to ASTM C 1202, adding clastic sand to the G35 mix reduces chloride ion penetration from low to extremely low levels. This is because of the development of better bonding between cement paste and aggregates. Also, at higher levels of sand replacements with clastic sand show cracks at the interfacial transition zone thus durability is reduced [26]. The mix with 35% of GGBS and 20% of clastic sand is optimum for reducing the chloride ion permeability in concrete.

3.2. Acid attack test

To determine the concrete quality when exposed to an acidic environment, acid attack test has been carried out as per ASTM C 267 [27] The 28-day percentage of weight loss has been recorded and exhibited in Fig.2. From Fig.2 it is observed that the addition of GGBS in place of cement minimizes weight loss when exposed to an acidic environment. The use of 15% GGBS as a substitute for cement results in a 1.4% reduction in concrete weight loss as compared to the control mix. Similarly, increasing the amount of GGBS reduces weight loss in concrete by up to 35%. The inclusion of 35% GGBS in place of cement reduces the weight loss of concrete. Further, the sand has been replaced with clastic sand in the G35 mix. The accumulation of 10% of clastic sand in the G35 mix exhibits a 19.5% decrease in weight loss as compared to the control mix. The accumulation of 20% clastic sand in the G35 mix exhibits a 21.5% reduction in weight loss as compared to the control mix. Likewise, the accumulation of 30% and 40% of clastic sand in the G35 mix exhibits an 18% and 16.5% decrease in weight loss in contraction with the control mix. This is due to the pozzolanic activity of GGBS and the development of strong bonding between clastic sand and cement.

3.3 Sulphate attack test

It is a critical test method for assessing the durability of concrete in sulphate-rich environments. The 28-day water-cured samples are utilized for this study. The cubes are removed from the water and cured in water containing 10% of Na2SO4. The weight after 28 days has been recorded and exhibited in Fig.3. From Fig.3 it is observed that the test results follow the identical trend as of the acid attack test. The replacement of GGBS in place of cement exhibits greater resistance to surface deterioration when exposed to a sulfate environment. The replacement of 15% of GGBS exhibits a 0.98% reduction in weight loss in contraction with the control mix. Likewise, the replacement of 25% and 35% of GGBS in concrete exhibits a 7.8% and 11.6% reduction in weight loss in contraction with the control mix. The addition of 45% of GGBS exhibits an increase in weight loss as compared to the mix G35. Further, the inclusion of clastic sand in the G35 mix enhances the resistance toward sulphate attack. The replacement of 10% clastic sand as a substitute for fine aggregate in the G35 mix exhibits a 17.5% reduction in weight loss in compared with the control mix. Likewise, the replacement of 20% and 30% of clastic sand instead of fine aggregate in the G35 mix exhibits a 19.5% and 16.4% decrease in weight loss in compared with the control mix. The replacement of 40% clastic sand instead of fine aggregate in the G35 mix exhibits a 14% reduction in weight loss in contraction with the control mix. The accumulation of clastic sand shows a better bond between the cement and aggregates. Thus, the durability of the concrete wiil be enhanced.

3.3. Water Permeability Test

In this investigation, the test was done on all concrete mixes in triplicate according to DIN 1048 standards [27-29]. The depth penetration of water is recorded by the application of pressure in the range of 0.1 and 0.7 MPa. The test results are depicted in Fig.4. From Fig.4 it is identified that increasing the dosage of GGBS as a replacement for cement decreases the water penetration depth. The addition of 15% of GGBS in the concrete mix exhibits a 5% reduction in the water penetration depth in comparison with the control mix. The replacement of 25% and 35% of GGBS in place of cement exhibits a 12.5% and 17.4% decrease in the water penetration depth in contraction with the control mix. Similarly, the accumulation of 45% of GGBS enhances the water penetration depth in contraction with the mix G35. Further, clastic sand has been added to the G35 mix to make the concrete sustainable. The inclusion of 10% clastic sand in place of fine aggregate in the G35 mix exhibits a 25% reduction in the water penetration depth in contraction with the control mix. Similarly, the inclusion of 20%, 30%, and 40% of clastic sand in place of fine aggregate in the G35 mix exhibits a 32.5%, 30%, and 27.5% reduction in the water penetration depth in contraction with the control mix. The GGBS enhances the hydration process by pozzolanic activity thus dense structure has been developed. Also, the accumulation of clastic sand enhances the bonding between the fine aggregate and cement particles. Thus, the durability of concrete has been enhanced.

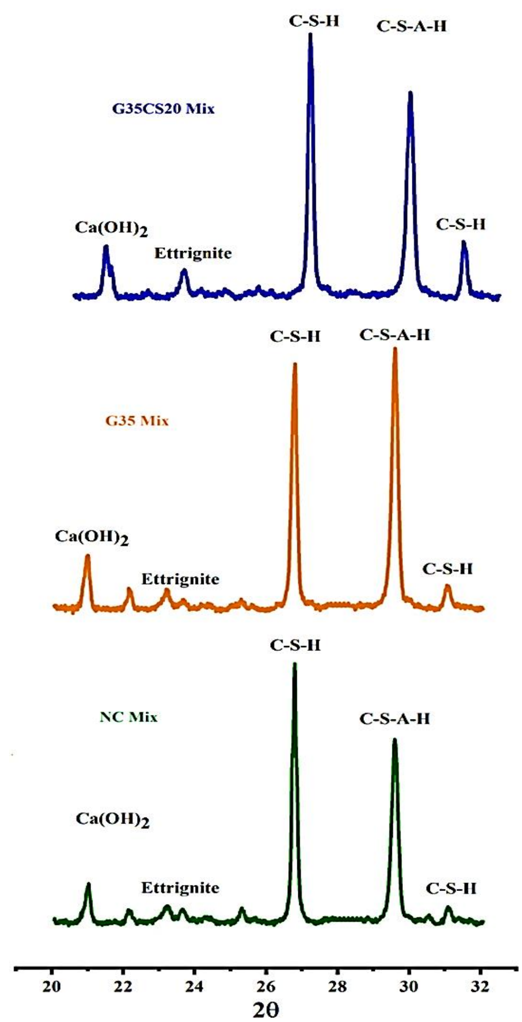

Figure 5. XRD Analysis of different mixes

3.4. XRD analysis

X-ray diffraction (XRD) analysis was employed to examine the morphology, chemical bonding, and hydration products. The database available in X'Pert High Score Plus software was utilized for this analysis. The test was done on the control mix, G35 mix, and G35CS20 mix, respectively. The details of the XRD analysis are shown in Fig.5. From Fig.5 it is identified that the presence of ettringite, CSH, Ca(OH)2, and little calcite peaks are identified in all concrete mixes. It confirms that better hydration products have been generated in all concrete mixes with and without the addition of GGBS. Also, the higher peaks of the CSH are identified in the mixes G35CS20 and G35 in contraction with the control mix. It confirms that higher amounts of CSH gel have been formed in these mixes by the pozzolanic activity of GGBS.

4. Conclusion

The need to develop a sustainable concrete has grown at a quick rate recently. Many studies have been done to mitigate the negative effects caused by concrete. Thus, this investigation was undertaken to lessen the negative effects while improving the quality of concrete. The results of replacing cement with GGBS and fine aggregate with clastic sand are summarized below.

- The replacement of GGBS in place of cement enhances the durability of concrete and makes concrete sustainable by minimizing cement usage. The accumulation of 35% of GGBS is optimum for improving durability. There is a maximum reduction of 17.5% in water permeability of concrete in comparison with the control mix by the inclusion of 35% GGBS.
- The inclusion of clastic sand in the G35 mix further enhances the durability of concrete. The acid and sulfate attack test results confirm that the inclusion of 20% clastic sand and 35% GGBS is optimum for increasing durability.
- There is a maximum reduction of 21.5% and 19.4% in the weight loss of concrete that has been identified when concrete is exposed to acidic and sulfate environments in contraction with the control mix.
- The GGBS acts as a pozzolanic material and improves the hydration process. Further, the presence of silica in clastic sand generates better bonding between the aggregates and cement paste. Thus, the durability of concrete becomes enhanced.
- This study confirms that the utilization of 35% of GGBS as a cement replacement and 20% of clastic sand as a fine aggregate replacement enhances the performance of concrete.

Authors' contribution

Talluri Maheswararao: conceptualization of research, drafting the research manuscript, reviewing, editing, and preparation of the final draft. P. Valli: Data collection, manuscript review, and editing.

Declaration of competing interest

The author(s) affirm that they have no conflicts of interest to disclose.

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Data Availability

The data and images utilized in this study were acquired and processed firsthand by the researchers for use as primary research materials. Requests for data sharing can be accommodated upon reasonable inquiries directed to the research team.

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