Ground granulated blast furnace slag concrete : promising and environment friendly building material for sustainable construction

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Abstract

Cement industry is one of the major contributors of greenhouse emissions. To achieve the Sustainable Development Goals (SDGs) and enhanced economic growth, use of alternative cementitious materials play a crucial role by reducing virgin material usage, reduced carbon foot prints, economical and eco friendly approach in sustainable construction practices. This work aims to incorporate Ground Granulated Blast Furnace Slag (GGBS), an industrial byproduct, in concrete mixes used in aggravaded environments. The compressive strength of two different combinations of OPC and GGBS, Sulphate Resistance Cement (SRC), OPC and Flyash was determined. The Mix specimens with equal amounts of OPC and GGBS showed good strength gain both in 7- and 28-days curing. Hence, a 50% incorporation of GGBS with OPC proves to be beneficial in strength gaining of the concrete samples reducing nearly 50% of emissions from virgin cement production. This would also ensure economic benefits by contributing to a greener and cleaner environment.

Keywords: OPC, SRC, GGBS, Compressive strength, SDGs and carbon foot prints.

Introduction

India the fourth largest economy in the world, focuses on infrastructure development and has a lot of potential for development in the construction sector. The construction industry in India is the second largest industry and accounts for about 11% of Gross Domestic Product. Focusing on achieving the Sustainable Development Goals (SDGs) - Agenda for 2030, Indian concrete industry is striving hard to reduce the carbon foot prints through many initiatives. One of the very promising ways to reduce carbon foot prints by the concrete industry is utilizing industrial by-products in the production of concrete like flyash, ground granulated blast slag, silica fume etc. While concrete is a popular construction material which is commonly used and prepared from locally available potable water, crushed stone, sand and cement. Incorporation of industrially originated waste which is huge in quantity, difficult to recycle and ends in landfill usually disturbs the ecological balance and hence these waste materials can be effectively reused in concrete preparation to reduce the use for virgin nonrenewable materials used for the same.

The Indian construction industry makes a significant contribution to the national economy and provides employment to a large number of people. Drawbacks like CO_2 emission, excessive river sand mining makes its use unsustainable. Moreover, India ranks the second place in cement production worldwide with 444.2Mt cement produced during 2024, and is expected to grow 800 Mt by 2030 (BEE, 2024). Cement consumption also expanded 6.2 per cent year on year in 2024 as per the report of ICD, 2025 in India. With the increase in demand and production capabilities, the Indian cement market needs to be developed as a sustainable industry by reducing the environmental impacts through less carbon foots from this sector.

This research work aims at utilizing GGBFS, an industrial waste, as cement substitute in the preparation of M40 grade concrete for a construction project situated near a polluted river side environment. Sulphate Resistant Cement (SRC) is usually used near marine or polluted environment with soil characteristics shows higher levels of chlorides and sulphates. GGBS incorporation in concrete may prove to be beneficial in resisting chlorides and sulphates in the surrounding aggravated environments which in turn would also led to higher durability of structural elements. Focusing on reduced carbon foot prints and positive impacts to the environment, this work also aims at aligning the UNSDGs with a key focus on Goal 9 (Industry, Innovation and Infrastructure), Goal 11 (Sustainable cities and communities) and Goal 13 (Climate action). Compressive strength of concrete cubes is tested by casting samples containing mixes with sulphate resistant cement, combination of OPC and Flyash and two different combinations of GGBS and OPC. Four sets of samples were casted, water cured and tested in control conditions as recommended by BIS and the results are discussed.

Literature

Babu and Kumar (2000) investigated the efficiency of GGBS in concrete mixes at various levels and found that the overall strength depends on age of curing and replacement levels. Oner et al (2007) in their experimental study found that the optimum percentage of GGBS as less than 55% from thirty-two mixtures. They also concluded that more than 55 % of GGBS replacement levels does not improve the compressive strength. Johari et al (2011) discussed the effect of supplementary cementitious materials and revealed that the addition of GGBS has increased the workability of concrete. Sunil et al (2018) while studying the effect of GGBS in different grades of concrete, found that the workability increases with the increase in GGBS content. The 40% replaced GGBS concrete achieved the highest compressive strengths and exhibited better durability in all test grades. Saranya et al, (2018) reviewed GGBS as cement replacement and concluded the optimum percentage lies between 40 to 45% by weight. Khan et al (2020) found their experimental work that the partial substitution of cement by optimal amount of Micro Silica (12%) in presence of GGBS (10%) can lead to enhancement of compressive strength. They also concluded that the replacement of cement with GGBS and Micro Silica leads to an increase in consistency and delay of the setting process. Ilaya raja et al, (2024) investigated the involvement of cement with GGBS in M20 concrete and found 10% replacement gained more strength than conventional concrete. This paper highlights the potential usage of GGBS in combination with OPC as binder in the production of M40 grade of concrete for substructure application in harsh environments.

Kalaiselvi and Sivagamasundari (2024), experimented 60% flyash and 40% GGBS to prepare M25 and M50 Geo polymer concrete and found that the M50 mix has achieved high split tensile strength, flexural strength, as well as compressive strength at 28 days than the conventional concrete. The effect of GGBS and Flyash as precursors to prepare engineered Geopolymer Composite and the effects of GGBFS content and curing time on the mechanical properties as well as the microstructure were investigated by Xinhua Cai et al (2025). They found that the incorporation of GGBFS significantly improves the composite compressive strength. This is attributed to the improved degree of reaction, which promotes the generation of C-A-S-H gels.

Materials and methods

For this work, 24 concrete cubes of size 150mm are prepared using locally available and good quality materials confirming to BIS standards. SRC confirming to IS 12330: 1988, Flyash confirming to IS 3812:1981 and OPC 53 grade confirming to IS 12269:2013 are used as binders and shown in figure 1. GGBS confirming to IS 16714:2018 was obtained from Salem, Tamilnadu, stored properly under dry conditions and having specific gravity 2.90, fineness 358 m2/kg was used without any lumps in this study in accordance with IS 16714:2018. Class F Fly ash from Ennore was used in this study. Well graded coarse aggregate from Wallajah, Tamil nadu, India with specific gravity 2.76, 0.67% water absorption and Zone II M.sand with no organic impurities was used as coarse and fine aggregates to prepare the concrete specimens. Clean potable water used met the requirements as per IS 456: 2000 and super plasticizer, Fosroc Auramix 400 was used at 0.5% in preparing all specimens.

Mix design is arrived as per IS 10262 for a designed slump 150+25mm. Materials for concrete preparation is placed in appropriate quantity in the mixer as shown in figure 2 and mixed properly by adding water and superplasticizer to form a consistent mix. Slump measurement was done at regular intervals and then 150mm x 150 mm cubes casted as per IS 456: 2000. The cubes were water cured for 7 and 28 days at ambient temperature. Then all the cubes are subjected to compressive strength test as per IS 516:1996 in a recently calibrated 2000kN capacity compressive strength testing machine. The obtained results are tabulated in the Table 1 given below.

Results and Discussions

The results of fresh and hardened concrete is discussed below explaining the methods and observations in detail.

Fresh concrete properties:

To understand the workability of fresh concrete with different binders, slump cone test as shown in figure 3 is conducted on all mixes and the slump drop is measured at regular interval of 30mins upto 3hrs from the time of water addition. The observed results are given below in the table.

Time (Min)	**Measured slump (mm)**			
	Mix 1 (85% OPC + 15% FA)	**Mix 2 (100% SRC)**	**Mix 3 (80% OPC + 20% GGBS)**	**Mix 4 (50% OPC + 50% GGBS)**
0	Collapse	Collapse	Collapse	Collapse
30	Collapse	Collapse	Collapse	Collapse
60	Collapse	Collapse	Collapse	205
90	200	205	Collapse	195
120	185	195	190	185
150	170	170	180	160
180	150	155	165	145

All mixes exhibited collapse slump till 60mins except Mix 4. Mix 4, with equal amount of OPC and GGBS as binder, found to be in a collapse stage till 30mins only. Later on, a 10mm slump drop for every 30mins was observed from 1hr till 2hrs and 15mm drop was observed from second hour up to 3hrs. Mix 3 with 20% GGBS exhibited collapse slump till 90mins and therafter, 10mm slump drop in the next 30mins till 150mins and 15mm drop was observed at the end of 3hour. Mix 2 with 100% SRC, retained collapse slump till 1hr and therafter a 10mm slump drop till 2hrs and 15mm drop from 2hrs to 3hrs. Mix 1 with OPC and Flyash, exhibited the collapse slump as same as Mix 2 till 1hr. A slump drop of 15mm observed in the second hour and 20mm at the last 30mins of the test. Hence, from the physical observation and slump measurements, Mix 3 exhibited a good slump retention when compared to all other mixes and Mix 4 is observed to have less slump retention when compared to other mixes. Addition of GGBS has increased the workability of concrete which is well understood from table 1 results.

Hardened concrete properties:

As per IS 516 the compressive strength test was conducted and the results obtained is presented in the table 2 below. Figure 4 shows the casted cubes and testing of cubes is shown in figure 5. The results show that the at 7 days curing, Mix 1 gained the least strength whereas Mix 4 gained highest strength. In 28 days Mix 4 gained the strength and Mix 3 strength gaining is the lowest of all. When compared to Mix 2 with SRC as binder, incorporation of GGBS in high volume has been proved to be beneficial when compared to low volume mix. Mix 3 with 20% GGBS has gained 7% less strength than Mix2 whereas Mix 4 with 50% GGBS has gained 4.5% more strength when compared to Mix 2. At 7 days curing, It is observed 8.7% less strength gain by Mix 1 and 4.3% by Mix 3 while, Mix 4 gained 10% more strength than Mix 2. Also, at 28days curing, mix 1 gained 1.1% and Mix 4 gained 4.5% more strength while Mix 3 observed 7% less strength gain when compared to Mix 2. Hence at both the curing periods, Mix 4 gained the best results among other mixes.

Table 1: Compressive strength results of samples

Mix designations	***Compressive strength in (N/mm2)***

	7 days	*28 days*
Mix 1 (85% OPC + 15% FA)	*37.60*	*54.8*
Mix 2 (100% SRC)	*41.20*	*54.20*
Mix 3 (80% OPC + 20% GGBS)	*39.40*	*50.4*
Mix 4 (50% OPC + 50% GGBS)	*45.33*	*56.64*

As observed and concluded by Johari et al (2011) and Sunil et al (2018), GGBS addition has increased the workability of concrete which is event from the slump test results. Higher percentage of GGBS incorporated concrete exhibited good strength which is well witnessed from the results of Mix 4 and as discussed by Sunil et al and saranya et al (2018). Compressive strength of concrete samples improved with increase in GGBS quantity and curing days inline with the results of Xinhua Cai et al (2025).

Conclusions

The experimental study has suggested the below suggestions

1.GGBS as binder when incorporated at an equal amount to OPC in concrete mixes has contributed to good strength gain both in 7 days and 28 days curing when compared with SRC concrete.

2. Incorporation of flyash has also proved to be beneficial with age as the results of Mix 1 has matched the results of Mix 2 at 28days of curing. But there is a lack in strength gain of Mix 1 initially compared to other mixes at the same age.

3. Both at 7 and 28 days curing, high volume GGBS incorporation has resulted in good strength gain indicating good initial and later strength gains which could be beneficial for quick strength gain requirement of structural members at aggravated environments.

Hence Mix 4 with equal amounts of OPC and GGBS as binder may be beneficial in all aspects to achieve sustainable construction with less carbon foot prints, more strength gain, economical and environment friendly to achieve SDGs.

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