


Sustainable utilization of cement kiln dust and GGBS in the development of eco-friendly concrete composite

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ABSTRACT

Concrete is an unavoidable element in modern construction. During concrete production enormous amount of CO₂ is emitted which results in global warming. From the point of view of environmental protection, sustainable concrete production should be focused on. An eco-friendly solution to lessen the impact on the environment has been briefed in this article. Ground Granulated Blast furnace Slag (GGBS) and cement kiln dust have been partially replaced with cement. The strength and durability properties of GGBS and cement kiln dust-incorporated concrete were evaluated and presented. The optimal substitution percentage of GGBS and cement kiln dust was reckoned as 15% and 12% respectively. The test results fortified that the replacement of GGBS and cement kiln dust for cement in concrete becomes an eco-friendly solution from the point of view of quality and sustainability.

Keywords: GGBS; Cement Kiln Dust; Partial Substitution; Sustainability.

1. INTRODUCTION

In the modern era, rapid infrastructure development has become inexorable. As a largely used construction material, currently concrete plays an unavoidable role in the construction arena. The requirement of concrete exceeds day by day in developing and developed countries. In the production of concrete, cement is an important ingredient which gives strength properties to the concrete [1–7]. For 1 tonne of cement production, nearly 1.85-ton tons of limestone is utilized which tends to lack of resource availability. Production of concrete also results in global warming because, during hydration process of concrete production, one tonne of concrete emits one tonne of CO₂ which results in global warming. On the other hand, continuous resource exploitation results in resource depletion in the environment. Nowadays, mining authorities implemented several judicial restrictions to explore natural resources [8–15].

As a result of the industrial revolution with cutting-edge technologies, innumerable by-products are produced during the production process and accumulated over some time. In most of the cases, these by-products are unscrupulously dumped in open yards [16–19]. Disposal of these by-products in a safe and secure manner without causing any menace to the environment becomes a crucial task for the industries. Improper disposal of these by-products by industries not only causes serious damage to the environment but also affects human health [20–26].

In the parallel rails, scarcity of non-renewable natural resources directly affects the production rate of construction materials. Over-exploitation of resources also affects sustainability. To overcome this situation, a paradigm shift in the direction of material substitution becomes the order of the day [27–33]. The construction industry offers a great scope to utilize industrial by-products as the alternative to conventional materials. From the quality and serviceability point of view, it is very critical to make complete replacement of conventional materials [34–39]. Hence the concept of partial substitution is preferred and implemented in this study.

GGBS and cement kiln dust are the two industrial by-products continuously produced in a larger quantity on a daily basis by the steel and cement manufacturing industry [40–49]. Disposal of this by-product become a burden for these industries. This critical situation prompted the thought of converting industrial by-products as a construction material. In the arena of waste reduction, substituting industrial by-products for conventional concrete ingredients becomes a viable remedy. Appropriate utilization of by-products considerably reduces the

waste accumulation and the cost of concrete production [50–59]. To save the environment from degradation, the utilization of industrial by-products becomes the need of the hour.

2. EXPERIMENTAL PROGRAMME

To achieve the objectives the following ingredient materials were used for producing the GGBS and cement kiln-based concrete.

2.1. Materials

Portland cement confirming the standards of IS:12269:2013 [60] was used in this study. Cement kiln dust produced during cement production was partially substituted for cement in concrete. Cement kiln dust was collected from the ACC cement factory, Coimbatore, Tamilnadu. Similarly, GGBS obtained from the Salem steel plant was utilized. The chemical composition of Portland cement, cement kiln dust and GGBS are furnished in Table 1.

2.2. Mix proportioning of concrete

The mix ratio of 1: 1.63: 3.14 was used to prepare control concrete and concrete comprising cement kiln dust with GGBS. Water cement ratio was kept at 0.55 to study the properties of concrete. Mix design was done as per the standard procedure mentioned in IS 10262–2009 [61]. The mix proportion of the mix is shown in Table 2.

Two sets of mixes were used to identify the properties of cement kiln dust and GGBS-added concrete. Concrete containing GGBS was designated as GBS-series. 5, 10, 15, 20 and 25 wt% of cement was replaced by GGBS. Mixes were designated as GBS-5, GBS-10, GBS-15, GBS-20, and GBS-25, respectively. Mix comprising GGBS and cement kiln dust (GBSCK-series), cement kiln dust in the amount of 4, 8, 12, 16, and 20 wt% of was replaced along with optimal GGBS percentage. Mix ID used for the GBSCK-series is GBSCK-4, GBSCK-8, GBSCK-12, GBSCK-16, and GBSCK-20, respectively.

2.3. Test methods

The compressive and flexural strength of the concrete specimens were evaluated for the GBS and GBSCK series of mixes. Concrete specimens of size 100 × 100 × 100 mm and prismatic samples of size 100 × 100 × 500 mm were used to determine the compressive and flexural strength after 7 and 28 of curing.

Corrosion activity of reinforcement and resistance against acid attack of concrete were assessed. The influence of acid attack was deliberated after 10, 20, 30, 40, 50 and 60 days. Half-cell potential test was carried out as per ASTM C 876 to identify the corrosion activity. The potential difference between an intruded reinforcing bar and concrete has been assessed.

Table 1: Chemical composition of Portland cement, cement kiln dust and GGBS.

COMPONENT	OPC %	CEMENT KILN DUST %	GGBS %
CaO	61.99	25.38	39.6
Al ₂ O ₃	4.98	3.67	17.76
Mgo	2.96	5.42	7.11
Fe ₂ O ₃	3.92	2.94	1.79
SiO ₂	20.78	61.64	31.09
Na ₂ O	0.89	–	0.74
K ₂ O	0.46	–	–
Loi	1.83	0.95	1.91
Free CaO	2.19	–	–

Table 2: Mix proportion for 1 m³ concrete.

MIX	CEMENT (kg)	POTABLE WATER (LITRES)	FINE AGGREGATE (kg)	COARSE AGGREGATE (kg)
Control	380	209	619.4	1193.2

Scanning Electron Microscope (SEM) was used to analyze the microstructure of the concrete material. Cement kiln dust and GGBS-incorporated concrete samples were subjected to scanning electron microscopy. Based on the test results, the structure microstructure of the concrete matrix has been assessed.

3. RESULTS AND DISCUSSIONS

3.1. Compressive strength of GBS series mixes

GBS series of mixes revealed escalation in compressive strength up to 15% substitution of GGBS with cement for 7 and 28 days of curing. Control concrete gained 7 days compressive strength of 11.3 MPa. Mix GBS-15 gained a higher compressive strength of 27.43% at 7 days of curing. The control mix gained 21.8 MPa of compressive strength after 28 days of curing. Mix GBS-15 gained 23.8% higher compressive strength than that of the control concrete mix. Compressive strength increase was found in the mix GBS-15 for both curing spells than the control concrete. Changes in the particle size distribution that impact packing density and hydration kinetics, as well as possible differences in pozzolanic activity and increased water demand that result in a higher water-cement ratio and decreased strength, could all be contributing factors to the strength loss following a 15% replacement of GGBS. Figure 1 illustrates the compressive strength of the GBS series of mixes are shown in.

3.2. Flexural strength of GBS series mixes

In the independent proportioning of GGBS within the cement mantle, the maximum flexural strength was exhibited for the mix GBS-15. Mix GBS-15 exhibited 32.5% higher flexural strength than control concrete for 7 days of curing, as like compressive strength, the escalating trend was observed in flexural strength also for the mixes GBS-5, GBS-10 and GBS-15. A slight reduction in flexural strength was noted beyond the 15% substitution of GGBS with cement.

The percentage increase in flexural strength for the mix GBS-15 was found to be 36.7% at 28 days of curing. The increase in strength is due to the presence of GGBS which produces a monolithic form of C-S-H gel during hydration. SiO₂ content of the GGBS reacts with the Calcium oxide present in cement and forms stable calcium silicate composites which impart strength. The flexural strength variations of the GBS series of mixes are shown in Figure 2.

3.3. Compressive strength of GBSCK series mixes

GBS mixes indicated that 15% of GGBS can be substituted in the cement mantle as an optimal replacement percentage. Therefore the cement kiln dust has been substituted for the cement in tandem with the optimal percentage of GGBS in the proportions between 4% to 20%. The test results witnessed that the mix GBSCK-12 exhibited the highest compressive strength. Mix GBSCK-12 gained 19.6% and 23.4% higher compressive strength than the control mix after 7 and 28 days of curing. The compressive strength variations of GBSCK mixes are shown in Figure 3.

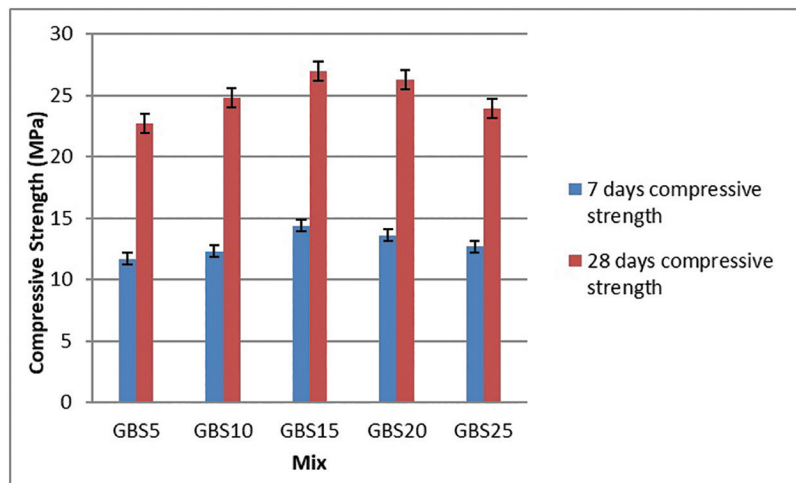


Figure 1: Compressive strength variations of GBS series of mixes.

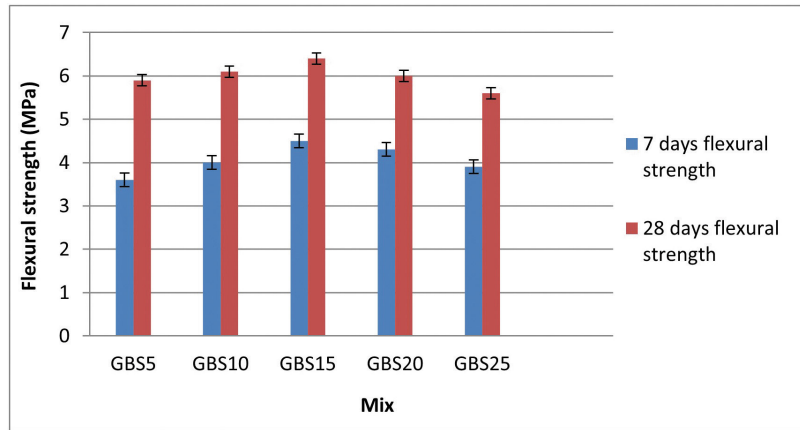


Figure 2: Flexural strength variations of GBS series of mixes.

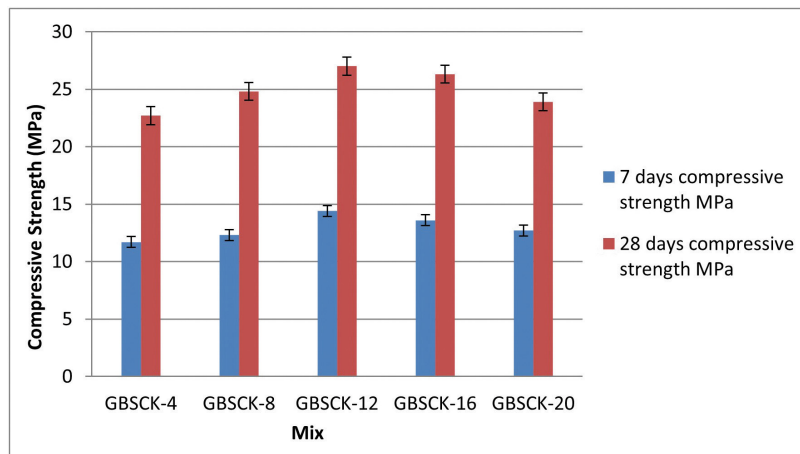


Figure 3: Compressive strength of GBS series of mixes.

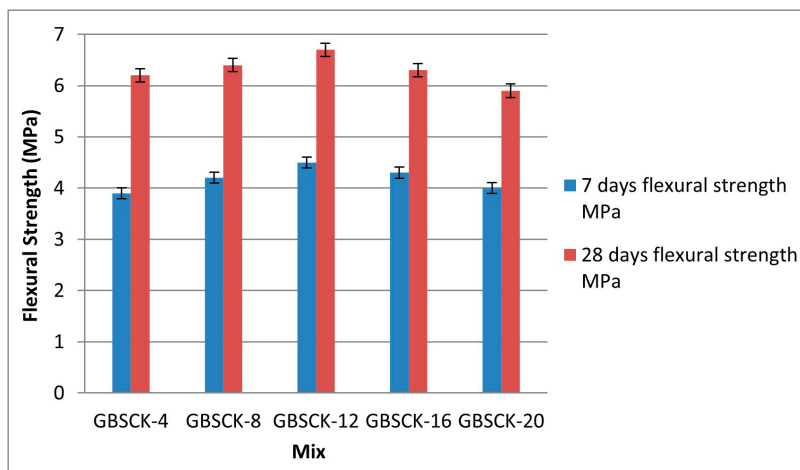


Figure 4: Flexural strength variations of the GBSCK series of mixes.

3.4. Flexural strength of GBSCK series mixes

Falling in line with the compressive strength, the experimental results subjected to flexural strength exhibit the same intensifying trend in flexural strength for the mixes GBSCK-4, GBSCK-8 and GBSCK-12. Significantly

mix GBSC-12 gained higher flexural strength among all the mixes. In terms of cement kiln dust replacement, a flexural strength increase of 19.6% was recorded for the mix GBSC-12 for 7 days of curing. In the case of 28 days of curing, a flexural strength rise of 12.3% was recorded.

It is evident that the replacement of 12% cement kiln dust with the optimal percentage of GGBS will enhance the strength of the concrete composite. Siliceous components found in cement kiln dust and GGBS create stubborn hydrates and enhances strength. The flexural strength of the GBSC group of mixes is shown in Figure 4.

3.5. Numerical correlation among compressive and flexural strength of GBSC mixes

Strength characteristics are foremost criteria to ensure the suitability of concrete. Drastic change in the development of strength was observed. Hence an empirical correlation was established between flexural and compressive strength of the GGBS and cement kiln dust-imbued concrete [54, 55]. Based on the experimentation, a regression analysis was carried out and the below-expressed relationship was developed to predict the 28 days flexural strength of GGBS and cement kiln dust imbued concrete, as expressed in Eq. (1):

$$\eta f = 0.0201 (\eta c) 1.3897 \text{ Mpa} \tag{1}$$

Where ηf and ηc represent the compressive and flexural strength of GGBS and cement kiln dust added to concrete for the curing spell of 28 days, expressed in MPa, respectively. The correlation coefficient shows that the developed empirical equation is at the dependability level of 94.6%. A higher percentage of dependability reveals the reliability of the developed empirical equation.

3.6. Corrosion assessment of rebar

The corrosion activity of rebar present in the mix GBSC-12 has been evaluated using the Halfcell potential test. The potential variance between rebar and the concrete composite has been assessed and related to control concrete. Once in a week, the potential variations were assessed and the test was performed up to the detachment of concrete from intruding bars due to extreme corrosion. Potential difference variations are an intangible measure to evaluate the corrosion activity induced in the rebar. The possibility of corrosion is less in the rebars of mix GBSC-12 than in the control concrete. Half cell potential values are shown in Figure 5.

3.7. Acid resistance of mix GBSEC-12

A concrete specimen of mix GBSC-12 has been tested against acid attack to determine the durability. Samples infused with GGBS and cement kiln dust were immersed in sulfuric acid. The influence of H_2SO_4 was investigated and the erosion due to acid attack in terms of weight loss percentage was deliberated. Weight loss percentage has been calculated after 10, 20, 30, 40, 50 and 60 days of acid curing. Test results evident that the weight

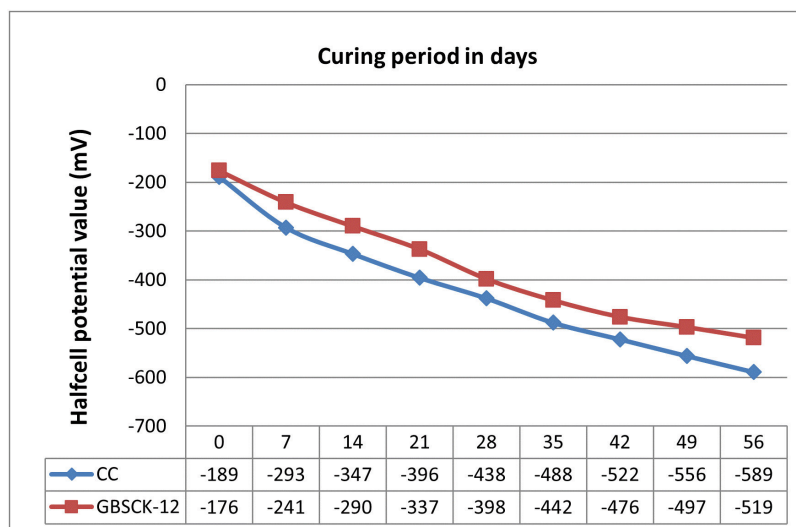


Figure 5: Potential difference variations of control and mix GBSC-12.

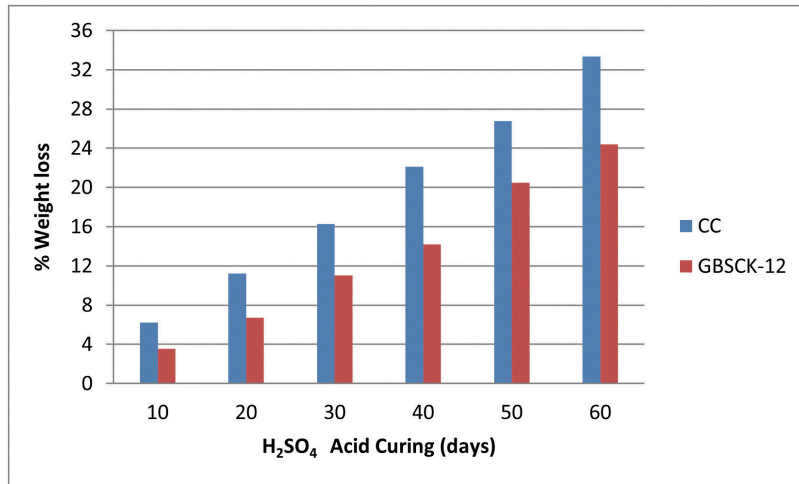


Figure 6: Percentage weight loss of control and GBSC-12 mix.

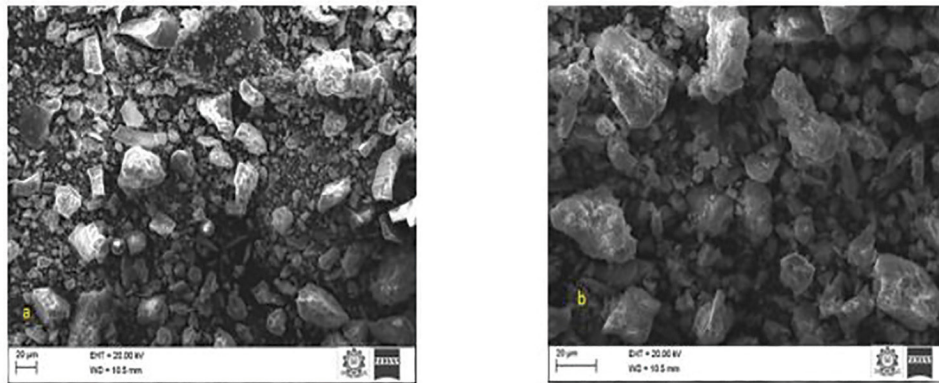


Figure 7: SEM image of (a) control concrete (b) GBSC-12 mix concrete.

loss percentage was less for the mix GBSC-12 than the control mix after various acid curing spells. After 60 days of acid curing, 33.3% weight loss was observed in control concrete. In the case of mix GBSC-12, only 24.5% weight loss was observed which strongly indicates the higher acid resistance of the mix GBSC-12. Higher resistance is due to the dense microstructure of the mix GBSC-12 which is because of pozzolanic action of GGBS and cement kiln dust in the matrix. Leaching of unstable hydrated products of control concrete tends to increase the weight loss of the sample. Weight loss variations of control and mix GBSC-12 are shown in Figure 6.

3.8. SEM analysis of GBSC-12 mix

SEM images of control concrete and concrete produced from the GBSC-12 mix are shown in Figure 7. SEM images revealed a denser microstructure in GGBS and cement kiln dust-incorporated concrete. This is due to the pozzolanic reaction of substitute materials in the concrete matrix. In the case of, conventional concrete, more pore spaces are found in the matrix and that may tend to destabilize the structural stability. This may be the reason for the lesser durability of conventional concrete compared with the GBSC-12 mix.

4. CONCLUSION

Test results exhibited the following possibilities of substituting GGBS and cement kiln dust with cement

- Without compromising the quality and characteristics of concrete, the cement mantle can be replaced with 15% of GGBS.
- In the case of cement kiln dust, 12% of cement kiln dust can be substituted for cement along with 15% GGBS.

- Based on experimentation, it is substantiated that mix GBSCK-12 achieved higher mechanical properties than the control concrete.
- Half-cell potential test significantly evident that partial substitution of GGBS and cement kiln dust extensively improved the corrosion resistance of steel.
- Mix GBSCK-12 gained higher acid resistance than the control concrete. The percentage weight loss of mix GBSCK was found 8.8% less than that of control concrete.
- From the foregoing discussions and SEM analysis, it is decisively concluded that a 12% replacement of cement kiln dust along with 15% GGBS in the cement mantle can produce an improvised eco-friendly and durable concrete mix.

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