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Mix Proportioning of Biochar as a Partial Replacement of Cement Using Alkaline Activators in Concrete Composite

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Abstract

The growth of the world population has led to a heightened need for housing, making construction a crucial sector. Cement, a critical element in concrete mixtures, is indispensable in construction activities. Yet, the diminishing reserves of natural resources such as limestone and rocks, essential for cement manufacturing, necessitate sustainable options. This research investigates the creation of sustainable concrete blends by incorporating biochar and ground granulated blast furnace slag (GGBS), activated with alkaline solutions (NaOH and Na_2SiO_3) at various concentrations (2, 4, 6, and 8). Demolition waste aggregates replaced coarse aggregate in varying mix proportions aimed at achieving maximum compressive strength. Findings revealed that using 100% GGBS with 100% coarse aggregate at 8 molarity resulted in a compressive strength of 66.20 MPa at 28 days. When incorporating 10% biochar into a mix of 100% GGBS at 8 molarity, the compressive strength reached 64.90 MPa at 28 days. It was noted that reducing GGBS from 100% to 25% and increasing biochar from 0% to 75%, alongside construction waste aggregates from 10% to 50%, led to a decline in compressive strength. Furthermore, higher molarity corresponded to increased compressive strength.

Keywords: Sustainable concrete composites, biochar, ground granulated blast furnace slag (GGBS), construction wastes, sodium hydroxide, sodium silicate, alkaline activators

INTRODUCTION

Concrete is a fundamental synthetic building material utilized in constructions such as buildings, bridges, roads, and dams. The materials involved in concrete production include cement, coarse aggregate, fine aggregate, water, and admixtures. Concrete is widely favored in construction due to its high strength, hardness, toughness, durability, and versatility during structural construction. These properties collectively make concrete a reliable and enduring choice in the construction industry. Despite its extensive use in construction, cement has significant drawbacks, particularly as one of the most highly consumed products. It releases a substantial amount of carbon dioxide annually, contributing to environmental pollution and harm. Moreover, cement production requires considerable mechanical energy. Cement substitutes are materials that can be used to varying degrees to mitigate these disadvantages during manufacturing processes [1].

The substitute cementitious materials, such as biochar and ground granulated blast furnace slag (GGBS), are finely divided substances that can

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replace cement in concrete production. Utilizing these alternative materials enables the manufacturing of sustainable concrete, which is an eco-friendly construction material and serves as an alternative to traditional Portland cement concrete [2]. Sustainable concrete is produced by utilizing waste materials such as biochar and ground granulated blast furnace slag (GGBS), along with alkali activators like sodium silicate and sodium hydroxide, in addition to both fine and coarse aggregates.

The idea of sustainable construction has become increasingly important due to growing environmental concerns, given that the construction industry consumes large quantities of natural resources and produces substantial waste, adopting sustainable practices is crucial to reduce its environmental impact. Concrete, as one of the most extensively used construction materials worldwide, significantly contributes to the consumption of natural resources. Due to its composite nature, which includes a binder, aggregates, and water, concrete is considered an ideal material for incorporating waste products [3].

Its widespread global use suggests that incorporating waste into concrete could lead to significant recycling opportunities. Given that aggregates make up approximately 60% to 75% of concrete constituents, any reduction in the reliance on natural aggregates would have profound environmental implications. Due to the environmental challenges posed by stone pits, including vibrations, noise, dust, and their significant impact on rural areas, the rate at which they can be exploited is often limited. Furthermore, the use of non-renewable materials adds to these challenges. Conversely, there is increasing interest in the use of construction and demolition waste (CDW) and other industrial wastes as alternative materials. Research and application efforts focus on replacing natural aggregates with these wastes to produce environmentally sustainable concrete [4].

Demolition waste, a type of construction waste, undergoes kiln treatment at high temperatures to harden, increase mechanical strength, and enhance moisture resistance. Depending on firing methods and manufacturing processes, it may vary in properties as depicted in Figure 1. It contains chemical elements like magnesia, silica, lime, alumina, and iron, making it practical for use in concrete production. Concrete incorporating demolition waste or clay offers `greater fire resistance compared to concrete made with natural aggregates [5-6].

Figure 1. Demolition Waste Aggregates, Biochar and GGBS.

The current understanding suggests that sustainable concrete based on biochar and GGBS exhibits the following properties:

- It has a structure resembling vitreous bodies.
- Sodium and potassium cations (Na+, K+) are present in the structure of sustainable concrete, though their bonding is not as strong as in zeolites, potentially leading to efflorescence (Figure 2).
- The material's structure is porous.
- The porous body of sustainable concrete contains water.
- Water is utilized in the sustainableization process as a means of transporting alkali activators.
- Amorphous hydrates and crystalline structures are observable in the material only when calcium-containing substances are present (i.e. blast furnace slag, calcareous biochar).

In recent years, research into sustainable concrete, termed "Sustainableization," has produced significant findings. Initially, Joseph Davidovits proposed a model describing the structure of hardened material, specifically focusing on a poly-sialate-silox type. Subsequent advancements, led by Barbosa, introduced a modified model that compared the structure to vitreous bodies, thereby enhancing our understanding of sustainable concrete properties [7].

The challenge in introducing new technology lies in acquiring the substrate, which also affects the development of production technology. Currently, volcanic tuffs are considered the optimal material for sustainable cement production, despite difficulties in sourcing due to limited deposits. Alternatively, using biochar from coal combustion and blast furnace slag from steel mills as substrates poses challenges in achieving material homogeneity due to their production processes [8].

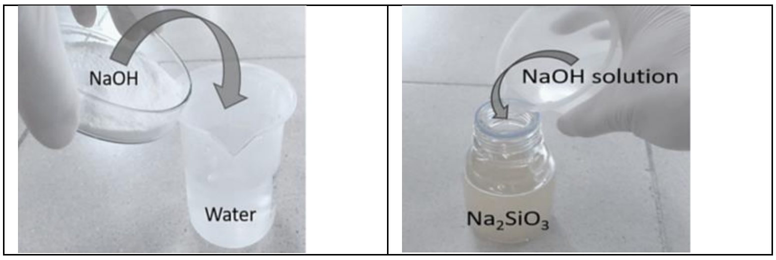

Figure 2. Alkaline Activators of NAOH and NA_2SIO_3

LITERATURE REVIEW

This research involved an experimental study to examine the impact of key parameters on the properties of concrete made with Jhama class Construction Waste. Various tests were conducted on both fresh and hardened concrete, using partial replacement of Jhama class Construction Waste as coarse aggregate in different proportions. The results revealed that with an 80% replacement of coarse aggregate, there was a reduction in compressive strength noted in both the initial and final cube tests, as well as in split tensile and flexural tests [9].

In this investigation, various tests were conducted on aggregates including impact value, porosity, and water absorption tests to determine the physical and mechanical properties of new and recycled crushed clay construction waste aggregate. Eight different types of aggregates were selected for the study, and their properties were compared with granite aggregate, which is known for being an excellent natural aggregate for producing Portland cement concrete. The research findings indicated that the relative densities of both new and recycled crushed construction waste aggregates be significantly lesser than that of granite aggregate [10].

In this study, the researcher chose ten different concrete mixes aiming for compressive strengths ranging from 20 to 50 MPa. Both conventional and recycled coarse aggregates were employed, and tests were carried out at various stages of concrete curing (1, 3, 7, 14, 28, and 56 days). Strain under maximum compressive stresses and modulus of elasticity were evaluated using concrete cylinders at the 28-day mark. The findings indicated that the compressive strength of recycled aggregate concrete (RAC) cubes and cylinders at 28 days averaged 90% of those using natural coarse aggregate under identical mix proportions. Furthermore, for concrete cylinders with compressive strengths of 20 and 30 MPa, the modulus of elasticity of RAC was only 3% lower compared to concrete containing natural aggregate. Consequently, the researcher concluded that the compressive strength of RAC is not solely determined by the strength of the demolished concrete used in producing recycled concrete [11].

In this investigation, an experimental study was conducted to evaluate various strength parameters, workability, fire resistance, and water absorption potential by replacing natural coarse aggregates with Construction Waste chips in standard concrete. Cubes and cylinders were cast and tested for compressive strength and split tensile strength after curing for 28 days. The results of the experiment indicated that the strength and properties of concrete using Construction Waste chips as coarse aggregate were satisfactorily comparable to those of concrete made with natural coarse aggregates. The researcher also reviewed previous studies on the use of demolished waste, particularly crushed Construction Waste as coarse aggregate in new concrete. The findings highlighted that the economic feasibility of recycling is a critical concern, given that the costs associated with sorting, screening, crushing, and transportation of demolished waste are nearly equivalent to those of natural coarse aggregate. Therefore, the researcher suggested that integrating the demolition process with these steps simultaneously could enhance economic efficiency, thereby reducing the overall cost of demolished waste [12].

The prologue of new sustainable binders for sustainable structures introduces a new aspect concerning the type of activator used. These activators, known for their strongly alkaline properties, vary in physical state, alkalinity, and chemical composition. Given that sustainable binders are primarily composed of waste materials or by-products from coal combustion or iron ore smelting, determining the exact impact of activators on their properties requires extensive trials, research, and observation [13].

This study explores the influence of alkali activators on key durability parameters of sustainable binders. Highly alkaline hydroxides, water glasses, and granules—themselves waste materials from various chemical processes—are used as activators. Biochar derived from coal and high-calcium ash from coal combustion serve as the substrates for these sustainable binders [14].

Assessed the collision of substituting sand aggregates (SA) with recycled structure waste aggregates (rBA) at different dampness states (saturated-surface-dry, partial dry, oven dry) at 0%, 50%, and 100% levels on the microstructure and sturdiness of concrete. The study revealed that replacing SA with rBA increased water absorption, carbonation, drying shrinkage, and water sorptivity, while plummeting chloride migration. Microscopic examination showed that as the proportion of recycled construction waste aggregates (rBA) increased, there was deterioration in the pore structure of the concrete due to the porous nature of rBA. Additionally, a pozzolanic reaction occurred between rBA and the cement matrix, leading to the consumption of $Ca(OH)_2$ crystals. This reaction produced hydration products that densified the interfacial zone, thereby improving adhesion between the cement matrix and rBA. These efforts aimed to enhance the properties of recycled construction waste aggregate concrete (RBAC) [15].

The study implemented fiber-reinforced polymer (FRP) jacketing to enhance corrosion resistance and to confine concrete. Concrete samples were prepared with varying percentages of replacement of recycled construction waste aggregates (RBA) (0%, 15%, 30%, 60%, and 100%) and different stiffness levels of FRP jackets (0, 1, 2, and 3 plies). Monotonic axial compression tests were conducted, revealing that higher RBA content reduced the efficacy of FRP confinement [16].

Substituted natural sand with recycled sand sourced from sintered clay Construction Waste (SCB) and recycled aerated concrete blocks (ACB) at levels of 10%, 20%, and 30% in mortar. The findings indicated that replacing natural sand with recycled sand from SCB and ACB led to an increase in mortar strength. Moreover, mortar incorporating recycled sand from SCB showed reduced shrinkage compared to that using recycled sand from ACB. This difference was attributed to the presence of micro-pores in SCB and ACB sand particles, which functioned as internal curing agents, thereby improving the microstructure of the interfacial transition zone between the cement matrix and recycled sand particles [17].

Explored the properties of fiber-reinforced concrete by replacing coarse aggregate with crushed Construction Waste. The research concluded that fibers had a significant impact on the compressive and tensile strengths of recycled concrete and improved water impermeability, although they did not affect gas permeability. The addition of PP fibers resulted in a denser microstructure in recycled concrete, reducing water absorption by 50% at a PP fiber content of 0.6 kg/m³. In another investigation,

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he studied axially loaded recycled Construction Waste aggregate concrete filled steel tubes (RBACFSTs). Substituting 50% of the recycled coarse aggregate with crushed clay Construction Waste reduced compressive strength by up to 3.8%. However, the use of crushed clay Construction Waste had minimal influence on structural behavior compared to its effects on material property tests, attributed to the confinement provided by the steel tubes [18].

Geopolymerization involves the use of an alkaline activator, with sodium/potassium silicate and sodium/potassium hydroxide (NaOH, KOH) being widely used choices. The activator type plays a crucial role in dissolving Al and Si ions from raw materials. Research by Prochon and Piotr emphasized that using NaOH solutions in the binding process of sustainable materials leads to higher condensation degree, compressive strength, lower crystallinity, and better acid resistance compared to those prepared with KOH solutions. Combining NaOH with water glass, which increases Si content in the sustainable mix, enhances the mechanical properties of the composite. Typically, in research, NaOH concentrations do not exceed 20M. Studies suggest that the ratio of sodium silicate solution to NaOH content should ideally not exceed 1.0 for optimal outcomes [19].

In fly ash (FA)-based sustainable materials, the sustainableization process is influenced by crystalline phases like mullite, hematite, or quartz. According to research by Fernandez-Jimenez et al., the composition of fly ash is critical for ensuring an effective binding process in sustainable materials. Reactive silica and alumina levels in fly ash must meet a minimum threshold to initiate the binding reaction properly. Biochar, which contains higher levels of calcium compounds, is more appropriately termed "alkali-activated materials (AAM)" for binders rather than "sustainable." Unlike sustainables, which typically require high temperatures for activation and solidification, AAM can be utilized under ambient conditions. In AAM, the primary hydration product is calcium-(alumino)-silicate-hydrate (C-(A)-S-H), whereas in sustainables, C-(A)-S-H coexists with sodium-alumino-silicate-hydrate (N-A-S-H). As more coal power plants transition to co-firing or integrate biomass combustion, it's essential to assess the suitability and quality of biochar resulting from these processes as potential binders for sustainable materials [20].

In this study, three distinct types of biochar from different sources and with varied chemical compositions were evaluated as potential precursors for alkali activation using various activators: silica biochar obtained from coal combustion (RFA), co-combustion biochar derived from coal and wood biomass (CFA), and biochar derived solely from biomass combustion (BFA). Each type of biochar underwent detailed analysis, including X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) tests, as well as scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS) attachment. Additionally, measurements were taken for density, loss on ignition, and particle size distribution [21-22].

RESEARCH SIGNIFICANCE

This research is significant as it aims to compare the compressive strength of Sustainable concrete using varying ratios of cementitious materials GGBS and Biochar (100:0, 75:25, 50:50, and 25:75) with different molarities of alkaline activators such as NaOH and Na2SiO3. Demolition Waste Aggregates are also utilized as coarse aggregates in the Sustainable concrete mixes. Recently, there has been a noticeable decrease in the capacity utilization of cement manufacturing plants, leading to the growth of a robust local Construction Waste industry.

The objective of Current Study

The project aims to achieve the following objectives:

1. Evaluate the workability of Sustainable concrete using GGBS and Biochar with different molarities, while replacing coarse aggregate with Demolition Waste Aggregates for M-20 design mix.
2. Investigate the compressive strength of Sustainable concrete through partial replacement of coarse aggregate with Demolition Waste Aggregates up to 50%.

3. Prepare Sustainable concrete using varying proportions of cementitious materials GGBS and Biochar (100:0, 75:25, 50:50, and 25:75) with different molarities of alkaline activators (NaOH and Na2SiO3) for M-20 design mix.
4. Analyze the compressive strength of Sustainable concrete across all molarities, incorporating different percentages of GGBS, Biochar, and Demolition Waste Aggregates.

Materials

In this research, three distinct alkaline activators, NaOH and Na2SiO3, were utilized. These substances are directly associated with their functionality and are derived as by-products from various chemical processes. They were applied to activate blends containing two mineral admixtures, GGBS and Biochar. The materials for this study were sourced from thermal power plants and steel mills [5].

i. Biochar
ii. Ground granulated blast furnace slag
iii. Fine aggregate
iv. Coarse aggregate
v. Alkaline Activators (NAOH, Na_2SiO_3)
vi. Demolition Waste Aggregates for partial replacement

To create the alkaline activator solution, a combination of Sodium Silicate and Sodium hydroxide is prepared using 1 liter of potable water for each mix. These activators create an alkaline environment necessary for GGBS and Biochar to release alumina and silica, crucial for forming Sustainable concrete. Sodium hydroxide solution is made by dissolving flakes in potable water to produce NaOH solution. It's recommended to prepare the solution at least 24 hours before use. Locally sourced 16mm aggregates were used as coarse aggregate, partially replaced by 16 mm Demolition Waste Aggregates, crushed to size using crushers. River sand serves as the fine aggregate in the mix, with SP-30 used across all Sustainable concrete mixes to enhance workability [6].

Methodology

The experimental work in Tables 1 & 2 focuses on evaluating the effect of varying percentages of overburnt Construction Waste on the compressive strength of Sustainable concrete containing GGBS and Biochar.

This research is significant as it aims to compare the compressive strength of Sustainable concrete made with different ratios of GGBS and Biochar (100:0, 75:25, 50:50, and 25:75) using various molarities of Alkaline Activators (NAOH and NA_2SIO_3), along with Demolition Waste Aggregates as coarse aggregates. Recently, there has been a notable decline in the capacity utilization of cement manufacturing plants, leading to the growth of a robust local Construction Wastes industry [7].

Table 1. Specification of alkaline substances used as activator

Symbol	Name of alkaline	SiO_2/Na_2O, molar module /molar mass*[g/mol]	Density[g/cm^3]	Viscosity cP(intemp.20^{0}C)
W1	Sodium hydroxide (NaOH)	None	2.13	None
W2	Sodium silicate Na_2SiO_3	None	2.6	None

Table 2. Chemical composition of Biochar and blast furnace slag used for research (mass %)

Symbol	Type	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_20	P_2O_5	Total
F1	Calcareous Biochar	45.17	21.79	4.58	1.85	1.49	21.06	0.23	0.19	-	96.36
G	Blast furnace slag	41.50	9.92	0.95	0.63	6.49	37.52	0.22	0.36	-	97.59

Describing a specific experimental setup where biochar, ground granulated blast furnace slag (GGBS), and powdered alkaline materials (sodium hydroxide and sodium silicate) were mixed in

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different proportions according to Table 3. This mixture was then activated to form a specific concrete blend for further investigation or study. This approach likely aims to explore the properties and potential applications of this composite material in concrete production.

The results of compressive strength tests for calcareous biochar mixed with ground granulated blast furnace slag (GGBS) and different molarities of alkaline activators (NaOH and Na_2SiO_3), as shown in Table 4. The findings indicate that compressive strength tended to increase with higher proportions of GGBS relative to biochar, as well as with increasing molarities of NaOH and Na_2SiO_3, ranging from 2 to 8. This suggests a positive correlation between these variables and compressive strength in the experimental mixes. This increase in strength can be attributed to the higher alkaline concentration, which enhanced the dissolution of Si^{4+} and Al^{3+} ions from GGBS and facilitated the formation of sodium and potassium alumino-silicates. The details are shown in Tables 3-6 and Figures 3-7 respectively.

Table 3. A compressive strength value of Sustainable Concrete with GGBS and Biochar mixes [MPa] with GG-100 : FA:0

$$\left(\frac{ALC}{Binder}\right) = 0.6 \ \& \ GG:100:FA:0$$

Time[days]	A1 (CA-100:BB-0)	A2 (CA-90:BB-10)	A3 (CA-80:BB-20)	A4 (CA-70:BB-30)	A5 (CA-60:BB-40)	A6 (CA-50:BB-50)
M2						
7	45.83	43.11	42.27	3720	35.06	32.93
28	46.54	43.33	42.61	39.40	36.12	33.09
M4						
7	50.94	49.48	39.84	38.68	35.69	31.05
28	51.53	49.72	43.69	42.05	36.63	31.12
M6						
7	51.84	48.29	46.28	41.10	36.85	31.96
28	54.03	52.94	50.77	41.65	38.47	33.21
M8						
7	62.91	61.64	50.26	41.25	37.64	34.18
28	66.20	64.90	59.22	42.43	39.90	36.06

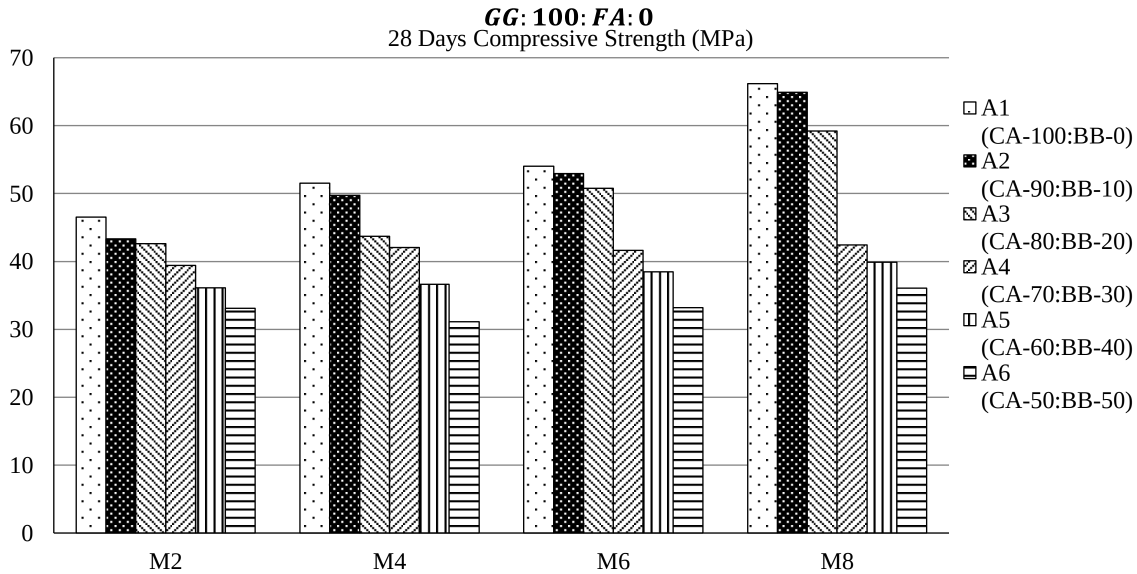

Figure 3. 28 Days Compressive Strength of GG-100: FA:0.

Table 4. A compressive strength value of Sustainable Concrete with GGBS and Biochar mixes [MPa] with GG-75: FA:25

$\left(\frac{ALC}{Binder}\right) = 0.6\&GG:75:FA:25$

Time[days]	A1(CA-100:BB-0)	A2(CA-90:BB-10)	A3(CA-80:BB-20)	A4(CA-70:BB-30)	A5(CA-60:BB-40)	A6(CA-50:BB-50)
M2						
7	34.87	34.69	33.31	32.76	31.69	30.70
28	38.97	37.71	35.93	33.72	32.69	31.01
M4						
7	41.96	42.36	40.08	37.08	36.37	31.02
28	48.01	44.16	42.17	38.54	36.72	32.69
M6						
7	44.97	45.11	41.32	38.47	36.06	33.15
28	50.48	46.33	44.60	38.97	36.33	34.01
M8						
7	51.98	52.76	44.39	41.51	40.04	36.60
28	61.83	59.29	54.02	47.95	42.40	39.11

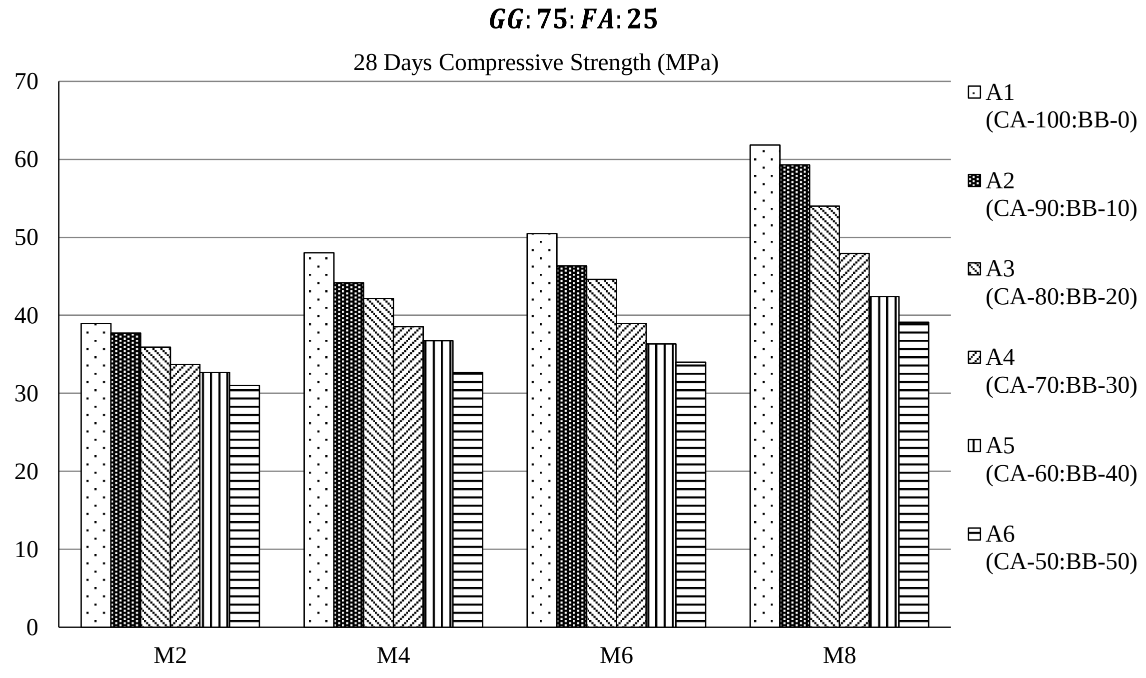

Figure 4. 28 Days Compressive Strength of GG-75 : FA:25.

Table 5. A compressive strength value of Sustainable Concrete with GGBS and Biochar mixes[MPa] with GG-50 : FA:50

$$\left(\frac{ALC}{Binder}\right) = 0.6\&GG:50:FA:50$$

Time[days]	A1 (CA-100:BB-0)	A2 (CA-90:BB-10)	A3 (CA-80:BB-20)	A4 (CA-70:BB-30)	A5 (CA-60:BB-40)	A6 (CA-50:BB-50)
M2						
7	26.12	26.85	27.54	26.73	25.33	21.01
28	29.43	28.35	28.13	27.76	26.43	22.82

M4						
7	25.35	25.58	23.90	21.02	24.65	17.81
28	28.16	27.88	28.51	27.06	28.77	21.02
M6						
7	31.06	31.86	30.63	29.75	24.05	18.34
28	33.97	32.33	32.53	31.79	27.45	24.12
M8						
7	27.79	26.05	31.22	30.94	29.82	25.85
28	38.13	37.56	35.89	33.32	33.40	29.62

$$\boldsymbol{GG: 50: FA: 50}$$

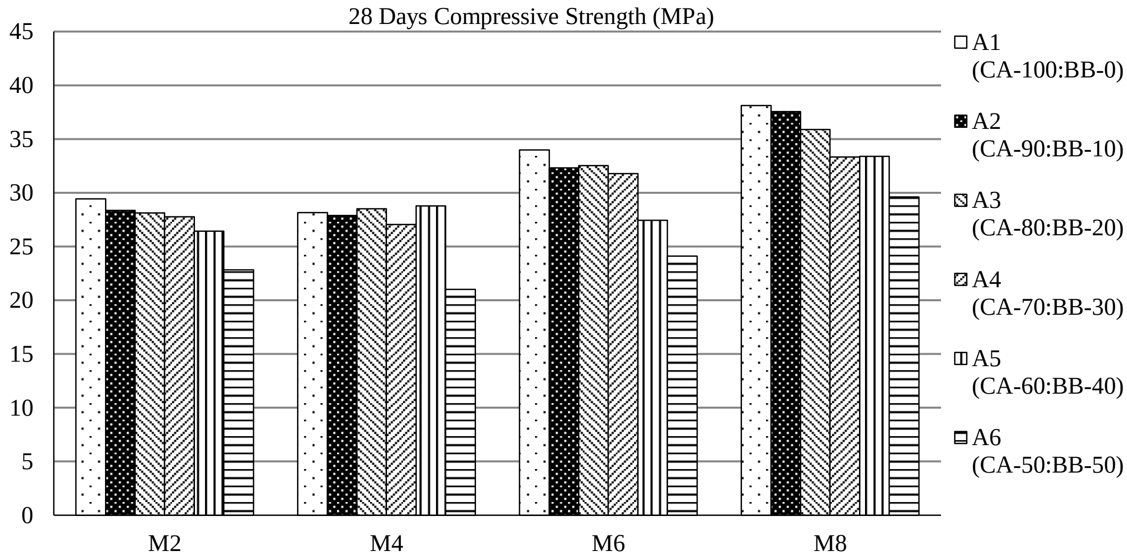

Figure 5. 28 Days Compressive Strength of GG-50 : FA:50.

Table 6. A compressive strength value of Sustainable Concrete with GGBS and Biochar mixes [MPa] with GG-25 : FA:75

$$\left(\frac{ALC}{Binder}\right) = 0.6\&GG: 25: FA: 75$$

Time[days]	A1 (CA-100:BB-0)	A2 (CA-90:BB-10)	A3 (CA-80:BB-20)	A4 (CA-70:BB-30)	A5 (CA-60:BB-40)	A6 (CA-50:BB-50)
M2						
7	20.84	19.89	17.87	15.61	14.50	12.74
28	21.02	20.95	18.28	16.21	16.41	14.89
M4						
7	21.07	20.84	18.77	16.50	16.81	14.06
28	24.01	21.83	20.54	18.15	17.36	16.50
M6						
7	21.97	21.06	19.51	17.17	17.02	15.43
28	25.94	23.82	20.71	19.14	18.40	16.33
M8						
7	22.01	21.98	20.51	18.75	18.03	16.28
28	29.89	26.76	23.86	22.14	21.16	20.53

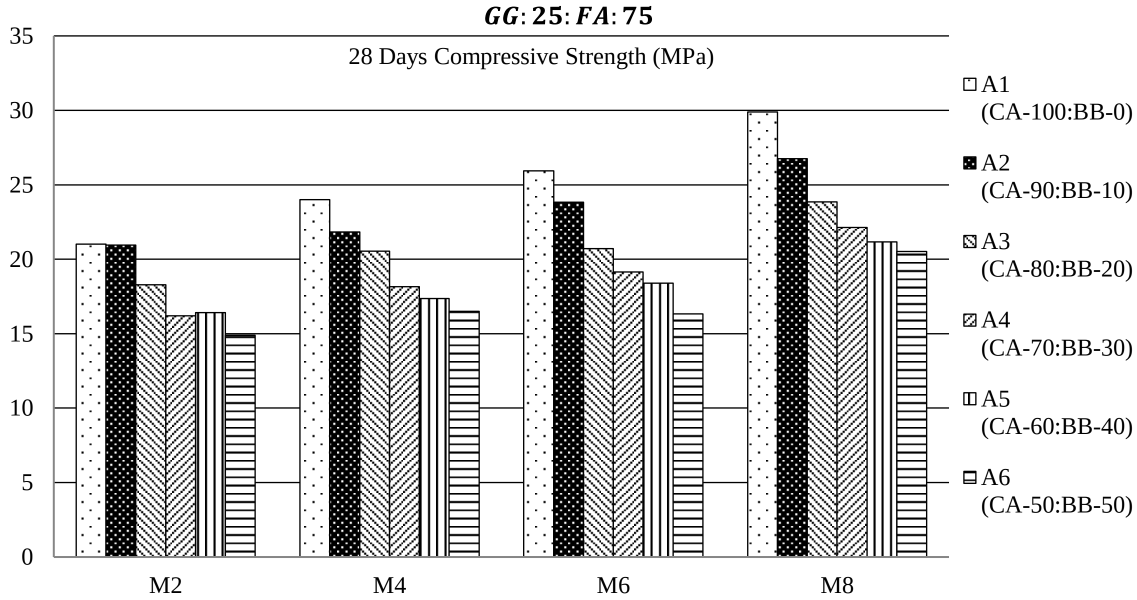

Figure 6. 28 Days Compressive Strength of GG-25 : FA:75.

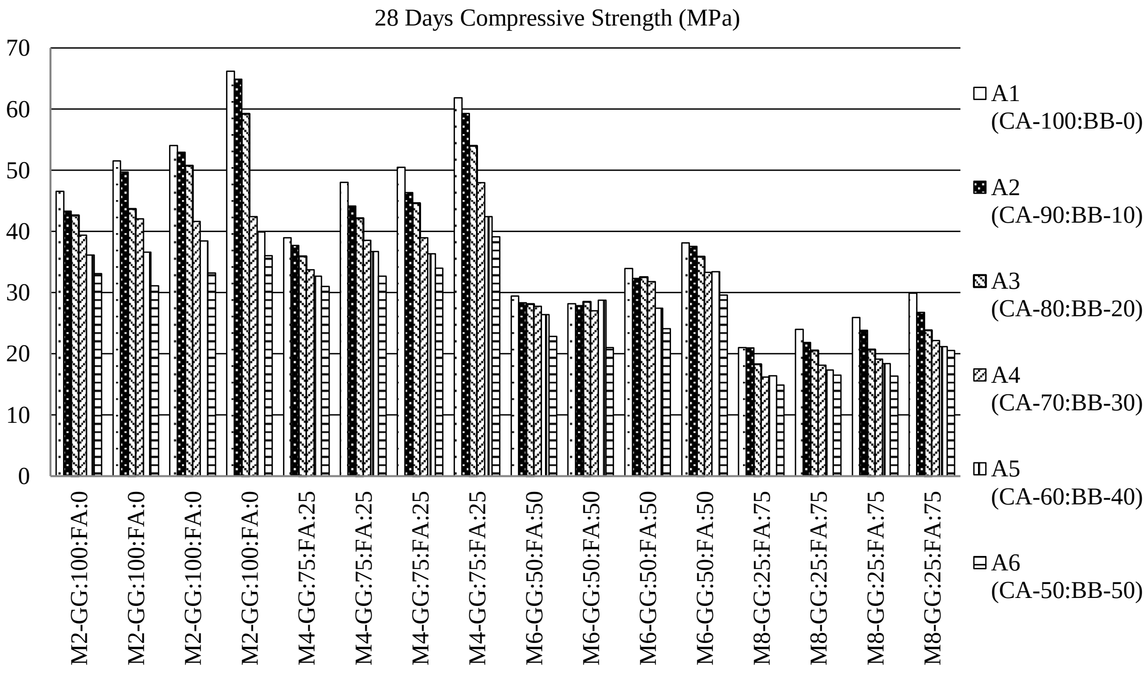

Figure 7. Compressive Strength of Sustainable Concrete with all Molarities including replacement of Coarse Aggregate with over Construction Waste

CONCLUSIONS

In this project, the focus was on evaluating the workability of Sustainable concrete using different molar ratios of GGBS and Biochar, while also replacing coarse aggregate with Demolition Waste Aggregates in the M-20 design mix. Additionally, the study involved testing the compressive strength of Sustainable concrete through partial substitution of coarse aggregate with Demolition Waste Aggregates, up to 50%. The research also included preparing Sustainable concrete with varying combinations of GGBS and Biochar (100:0, 75:25, 50:50, and 25:75) using different molarities of Alkaline Activators (NAOH and NA2SIO3) for the M-20 design mix. Furthermore, the compressive strength of Sustainable concrete was assessed across all molar combinations, considering different proportions of GGBS, Biochar, and Demolition Waste Aggregates.

Following are the closing observations that have been through based on the work conducted on Sustainable concrete:

1. Incorporating higher proportions of Ground Granulated Blast Furnace Slag (GGBS) in Sustainable concrete notably reduces setting time and aids in achieving strength.
2. Under conditions of 100% GGBS and 100% coarse aggregate (CA) at 8 molarity, the maximum compressive strength of GPC at 28 days is 66.20 MPa. With 100% GGBS and 10% Biochar (BB) at 8 molarity, the maximum compressive strength of GPC at 28 days is 64.90 MPa.
3. Decreasing GGBS from 100% to 25%, increasing Biochar from 0% to 75%, and increasing Demolition Waste from 10% to 50% as replacements for coarse aggregate result in reduced compressive strength of GPC.
4. Increasing the concentration of molarity enhances the compressive strength of Sustainable concrete.
5. The compressive strength of GPC with partial replacement of Demolition Waste Aggregates increases with longer curing times. However, significant strength gains beyond 7 days are minimal.
6. Addition of 1% SP-30 super plasticizer by mass of GGBS and Biochar enhances the workability of GPC.
7. Higher percentages of Biochar in the mix tend to decrease the compressive strength of GPC.
8. Utilizing GGBS, Biochar, and Demolition Waste Aggregates in concrete mixes proves beneficial for addressing environmental concerns and reducing the need for large quantities of cement and coarse aggregate.
9. GPC incorporating Demolition Waste Aggregates serves as a sustainable building material, contributing to cost reduction in concrete construction.

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