EXPERIMENTAL INVESTIGATION ON CONCRETE USING GGBS AS A PARTIAL REPLACEMENT OF CEMENT AND COAL BOTTOM ASH AS A PARTIAL REPLACEMENT OF FINE AGGREGATE

R. A. Gawade1,
Prof. A. A. Sengupta 2
1PG Scholar,Department of Civil Engineering,
DVVPCOE, Savitribai Phule Pune University, Ahilyanagar, Maharashtra, India
2PG Guide, Department of Civil Engineering,
DVVPCOE, Savitribai Phule Pune University, Ahilyanagar, Maharashtra, India

Article History: Received on: 04/04/2026
Accepted on: 12/06/2026

DOI: https://doi.org/10.26662/ijiert.v13i6.pp1-9

Abstract

Concrete is one of the most widely used construction materials, but its production, especially cement, has a high environmental impact due to carbon dioxide emissions. This study investigates the use of industrial by-products, specifically Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement for cement and Coal Bottom Ash (CBA) as a partial replacement for fine aggregate, in M25 grade concrete. Various concrete mixes with different replacement levels were prepared and tested for compressive strength at 7 and 28 days, as well as for workability and mix consistency.

The results indicate that the inclusion of GGBS and CBA can improve the strength and durability of concrete while promoting sustainable construction practices. Optimal replacement levels provide a balance between strength, workability, and environmental benefits. The findings suggest that GGBS and CBA can be effectively utilized in concrete, reducing the consumption of natural resources and minimizing industrial waste disposal issues.

Keywords: Ground Granulated Blast Furnace Slag (GGBS), Coal Bottom Ash (CBA), Compression strength, Flexural strength.

I. INTRODUCTION

Cement and fine aggregate are the two most important constituents of concrete, playing a major role in determining its strength, durability, and performance. However, the manufacturing of cement leads to high carbon dioxide emissions, and the excessive extraction of natural river sand causes severe environmental degradation. Hence, there is a growing need to identify suitable industrial by-products that can replace these conventional materials in concrete production. The use of such waste materials not only reduces environmental pollution but also promotes sustainable construction practices and the concept of “Green Concrete”.

Ground Granulated Blast Furnace Slag (GGBS) and Coal Bottom Ash (CBA) are two such industrial by-products that have shown promising results when utilized in concrete. GGBS is obtained from the blast furnaces of steel industries as a by-product in the manufacture of iron. When molten slag is rapidly cooled using water, it forms a glassy, granular material which, after grinding to a fine powder, is known as GGBS. It is rich in silica, alumina, and calcium oxide, which gives it cementitious and pozzolanic properties. When GGBS is used as a partial replacement for cement, it improves the durability, reduces heat of hydration, and enhances the long-term compressive strength of concrete.

On the other hand, Coal Bottom Ash (CBA) is a waste material generated from coal-fired thermal power plants. When pulverized coal is burnt in a dry bottom boiler, about 80 percent of the unburnt material or ash is entrained in the flue gas and is captured and recovered as fly ash, while the remaining 20 percent of the ash is dry bottom ash dark gray, granular, porous material collected in a water-filled hopper at the bottom of the furnace. Discarded bottom ash is either landfilled or sluiced to storage lagoons. The lagooned bottom ash is sometimes mixed with fly ash, forming pond ash. Approximately 30 percent of all coal ash is handled wet and disposed of as pond ash.

Thermal power plants in India generally dispose of and store the ash in large ponds. Fly ash is collected from electrostatic precipitators, and the remaining bottom ash is mixed with water and transported to ponds in slurry form. Pond ash or bottom ash, being coarser and less pozzolanic, is not widely used. However, its particle size distribution and fineness modulus are similar to that of fine aggregates, making it a potential alternative for river sand in concrete. The increasing demand for river sand in the construction industry has resulted in resource depletion and increased cost. Hence, utilizing bottom ash as a partial replacement for fine aggregate can serve as an economical and sustainable solution.

Similarly, the use of GGBS as a partial replacement of cement offers several benefits. India’s steel production generates millions of tonnes of slag every year, posing disposal challenges. Incorporating GGBS into concrete not only reduces the need for Portland cement but also enhances concrete’s resistance to sulphate and chloride attacks, minimizes thermal cracking, and increases long-term durability.

II. LITERATURE REVIEW

Zhang Wei et al 2024: This research investigates the combined utilization of Ground Granulated Blast Furnace Slag (GGBS) and Coal Bottom Ash (CBA) in sustainable concrete production. The study focused on mechanical strength, durability characteristics, and microstructural behavior of concrete containing different replacement levels of GGBS and CBA. The researchers observed that the incorporation of GGBS significantly improved the long-term compressive strength due to additional formation of calcium silicate hydrate (C-S-H) gel. Coal Bottom Ash acted as an effective alternative to fine aggregate because of its granular texture and particle size distribution. The study reported that workability slightly decreased with increase in CBA content due to higher water absorption. However, durability properties such as chloride resistance, sulphate resistance, and water permeability improved considerably. The optimum results were obtained at 20% GGBS and 30% CBA replacement levels.

Priyanka Sharma et al 2023: This research focused on the utilization of Coal Bottom Ash as partial replacement of fine aggregate along with GGBS as cement replacement in concrete. The experimental investigation included compressive strength, flexural strength, split tensile strength, and durability studies.

The study revealed that the compressive strength increased up to 15% GGBS and 30% Coal Bottom Ash replacement. The incorporation of GGBS reduced the heat of hydration and improved resistance to chloride penetration. The study concluded that combined utilization of GGBS and CBA can effectively produce sustainable and economical concrete with satisfactory engineering properties.

S Rakesh Kumar et al 2023: This study examined the durability behavior of concrete containing GGBS and Coal Bottom Ash under aggressive environmental conditions. The researchers evaluated chloride penetration resistance, acid resistance, sulphate resistance, and water absorption characteristics. The study concluded that the inclusion of GGBS significantly enhanced durability due to reduction in permeability and pore connectivity. Coal Bottom Ash contributed to improved resistance against sulphate attack because of its pozzolanic nature. The concrete specimens exhibited better long-term performance compared toconventional concrete.

S. Venkatesh et al 2022: This research focused on the use of Ground Granulated Blast Furnace Slag and Coal Bottom Ash in M25 grade concrete. Cement was replaced by GGBS at percentages ranging from 10% to 40%, while fine aggregate was replaced by Bottom Ash at percentages ranging from 10% to 50%. The study reported that compressive strength improved up to optimum replacement levels and gradually decreased beyond those levels due to higher porosity. The addition of GGBS improved durability and reduced heat generation during hydration. The researchers concluded that the combined use of GGBS and Bottom Ash is suitable for sustainable concrete construction.

Divya Patel et al 2022: This study investigated the microstructural characteristics and mechanical properties of concrete containing GGBS and Coal Bottom Ash. SEM analysis revealed that GGBS contributed to dense hydration products and reduced capillary pores in concrete. Coal Bottom Ash particles filled the voids between aggregates and improved packing density. The study reported enhanced compressive strength and reduced water absorption at moderate replacement levels. The researchers concluded that sustainable concrete with improved durability can be produced using industrial by-products.

Harish Kumar et al 2022: This research evaluated the influence of Coal Bottom Ash and GGBS on workability and strength characteristics of concrete. The researchers observed that slump values decreased with increase in Bottom Ash content due to rough texture and porous particles. However, compressive strength improved considerably at later curing ages because of pozzolanic activity. Split tensile strength and flexural strength also showed improvement up to optimum replacement percentages. The study recommended the utilization of Coal Bottom Ash in structural concrete applications.

M. Praveen et al 2022: This study investigated the durability performance of green concrete containing GGBS and Bottom Ash. The experimental investigation included water absorption, rapid chloride penetration, acid attack, and sulphate attack tests. The study concluded that GGBS significantly reduced permeability and improved resistance to aggressive chemical environments. Bottom Ash improved sustainability and reduced dependence on natural river sand. The combined use of these materials produced durable and eco-friendly concrete suitable for long-term applications.

J. Christopher et al 2021: This research investigated the strength and durability properties of concrete containing GGBS and Coal Bottom Ash. The researchers observed that compressive strength increased with curing age due to delayed pozzolanic reaction of GGBS. Coal Bottom Ash improved internal bonding and enhanced resistance to cracking. Water absorption reduced at optimum replacement levels because of dense microstructure formation. The study concluded that combined utilization of GGBS and Bottom Ash can effectively produce sustainable construction materials.

Khairunisa Muthusamy et al 2020: He investigates the effects of CBA on fresh, mechanical, and durability properties of concrete. The chemical and physical properties of CBA were diverse from various sources and years of investigation as it is influenced by the coal combustion system. Being rich in silica, CBA has pozzolanic characteristic. Many experimental works revealed that CBA can be used in appropriate proportion to enjoy the benefits of workability, enhanced concrete strength and durability. Almost all the researchers promote the idea of turning variety of wastes to wealth to save valuable green area for better use rather than dumpsite and reduce high dependency on river sand mining supply to ensure the sustainability of green river environment for prosperity of all the nations. The effects of using coal bottom ash on flexural strength of concrete are similar to those on the compressive strength. Some researchers noted an increase in the flexural strength for certain proportions, whereas, others reported a decrease for all the proportions. Coal bottom ash can not only be used as a fine aggregate but also as a partial cement replacement in the production of concrete.

Einstine M. Opiso et al 2019: This study was conducted to investigate the laboratory and field performance of PC while incorporating coal fly ash (CFA) as partial cement replacement and fine sawdust (FSD) as internal curing agent and filler admixture. Tests were performed in accordance with American Society for Testing and Materials (ASTM) standards. In general, the test results showed that PC with CFA and FSD as additives in PC gained enough strength to be considered for field application. In-situ infiltration and strength results showed that the pavement conformed to the typical values for a functional PC pavement. Based on the results, the selected design mix ratio of 1:3.5, at a w/c ratio of 0.35 for the PC with CFA and FSD passed the compressive, flexural and permeability requirements and it was within the typical range of values for both strength and permeability properties of a wellfunctioning PC pavement as per NRMCA. The laboratory assessment revealed that the blended PC showed no significant difference compared to the plain PC. This implies that the use of cement could be minimized up to 10% in blended PC with CFA and FSD without compromising its strength and permeability performance.

Kiran Kumar M et al 2018: This research is done to study the possibilities of replacing the part of fine aggregate by Bottom ash. Because of storing issues, the waste negatively affects the environment. To solve this problem, an attempt was made to check the effectiveness of bottom ash as a partial replacement of fine aggregate. Fine aggregate was replaced up to 50% bottom ash by the weight of fine aggregate and evaluating its compressive strength, split tensile strength and flexural strength. The optimum gained after 7 and 28 days curing period was found to be 10% bottom ash + 90% fine aggregate.

Prashant Kumar Sharma et al 2017: This research investigates The Experiments study indicates that Pond ash as a partial replacement of fine aggregate shows beneficiary effects over mechanical properties of concrete. The test results indicate that optimum Pond ash replacement is 15%, where there is a relative increment of compressive strength was obtained up to 13.65%. The bulk density and specific gravity of Pond ash is lower to Fine aggregate causes decrement in unit density of concrete. The main aim of this study is to use hazardous waste by product into building industry to achieve economical and eco-friendly concrete. On replacement of Pond ash partially with Fine aggregate in mix B1 (5% replacement), B2 (10% Replacement), B3 (15% replacement), B4 (20% replacement), B5(25% Replacement), it is observed that the Unit weight of Pond ash Concrete reduces by 1.77 % to 18.89 % respectively in comparison to B0. The unit weight of concrete gets reduced through the addition of pond ash as replacement of fine aggregate since it has lower specific gravity than fine aggregate.

G dineshkumar et al 2016: present research work presents the experimental investigation carried out to study the behavior of concrete using coal bottom ash at different replacement level of sand. As now-a- days construction work is increasing day by day all over the world, our natural sources are depleting at a rapid rate. So, to overcome this issue the present research was aimed to evaluate the potential of coal bottom ash as a partial replacement of sand in concrete by 0%, 10%, 20% , 30%, 40%, and 50% . In order to study the mechanical properties of concrete, M25 grade was fixed. Cubes, cylinders were casted and cured for 7 and 28 days. Cubes are tested for compressive strength, cylinders for splitting tensile strength. Compressive Strength of concrete is maximum at 20% replacement with a value of 21.25 N/mm2, 33.21 N/mm2 at 7days and 28 days respectively and with further increase in the percentage of replacement there is decrease in the strength of concrete. The split tensile strength of concrete is maximum at 20% replacement with a value of 3.10 N/mm2 and 3.93 N/mm2 at 7 days and 28 days respectively and with further increase in the percentage of replacement there is decrease in the strength of concrete.

A.sofi et al 2015: This article examines the The flexural behaviour of plain and fibrereinforced pond ash concrete (FRC) beams under monotonic loading condition. The beams were cast using three different percentages of pond ash, namely, 10%, 20% and 30% by weight of cement. Grooved type steel fibres were incorporated at different percentages of 0.5%, 1% and 2% by volume of concrete. Beams of cross section 150 mm · 150 mm and length 700 mm were tested in flexure under three-point bending system (one loading point plus two simple supports). Addition of fibres increased the failure load of the beams and ensured ductile behaviour. When pond ash content increased for a given steel fibre content in the beams, ultimate load increased. For example, in beams with 10% pond ash + 2% steel fibre, the increment was about 30% when compared with that of 10% pond ash beams of 0% steel fibre. When pond ash content of 20% was added to 1% steel fibre, the increment was about 43% when compared with that of beams with 0% pond ash + 1% steel fibre. When the pond ash content increased to 30%, for 1% fibre content, the increment was 43% when compared to 0% pond ash + 1% steel fibre. Similarly, for a given pond ash content in beams, when steel fibre increased, ultimate load increased. The ultimate load of beams with 0% pond ash + 2% steel fibre increased by 49% when compared with that of beams with 0% pond ash + 0% steel fibre.

III OBJECTIVES OF INVESTIGATION

- To investigate the physical and chemical properties of Ground Granulated Blast Furnace Slag (GGBS) and Coal Bottom Ash (CBA) and evaluate their suitability as partial replacement materials for cement and fine aggregate in M25 grade concrete.
- To study the fresh and hardened properties of concrete containing GGBS and Coal Bottom Ash, including workability, compressive strength, split tensile strength, flexural strength, and water absorption characteristics at different curing ages.
- To analyze the combined effect of GGBS and Coal Bottom Ash on the strength, durability, and long-term performance of concrete and determine the optimum replacement percentage for achieving improved mechanical and durability properties.
- To assess the environmental and economic benefits of utilizing industrial by-products in concrete, with the aim of reducing cement consumption, conserving natural river sand, minimizing industrial waste disposal, and promoting sustainable green concrete for infrastructure development.

IV. MATERIALS

1. Cement: The term cement is commonly used to refer to powdered materials which develop strong adhesive qualities when combined with water. Cement used in the investigation was 53 Grade Ordinary Portland cement.
2. Fine aggregate: River sand is used as a fine aggregate. Among various characteristics, the most important one for fine aggregate is its grading. Coarser sand may be preferred as finer sand increases the water demand of concrete and very fine sand may not be essential in fine aggregate as it usually has larger content of fine particles in the form of cement and mineral admixtures such as fly ash, silica fume etc. The sand particles should also pack to give minimum void ratio. Properties such as gradation, Specific gravity and water absorption have to be assessed to design a dense fine aggregate mix with optimum cement content and reduced mixing water. The river sand was used as fine aggregate confirming to zone 2.
3. Coarse aggregate: The nominal maximum size of coarse aggregate should as large as possible within the specified limits but in no case greater than one fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and fill the corners of the form. Locally available crushed stone with size varying from 12.5mm to 20mm aggregates are used.Coarse aggregate forms the major volume of concrete and contributes to strength and stability.4. Ground Granulated Blast Furnace Slag (GGBS): Ground Granulated Blast Furnace Slag (GGBS) is a by-product obtained from the iron-making process in steel plants. It is formed when molten slag from the blast furnace is rapidly cooled by water or steam, producing a glassy, granular material. GGBS has been introduced into the concrete industry as a partial replacement for cement to conserve natural resources and reduce environmental pollution caused by cement production. GGBS is rich in chemical compounds such as SiO_2, CaO, Al_2O_3, and MgO, which are highly reactive in the presence of water. These compounds

International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696 Website: ijiert.org
Volume 13, Issue 6, June – 2026

participate in the hydration reaction, forming additional calcium silicate hydrate (C-S-H) gel, which improves the strength, durability, and density of concrete. The use of GGBS in concrete not only enhances long-term compressive and tensile strength, but also reduces heat of hydration, making it suitable for mass concrete structures.

5. Coal Bottom Ash (CBA) : Coal Bottom Ash (CBA) is an industrial by-product obtained from coal-fired thermal power plants during the combustion of pulverized coal. During the generation of electricity in thermal power stations, coal is burnt at very high temperatures inside the boiler furnace. The combustion process produces two major ash products namely Fly Ash and Bottom Ash. The finer particles rise with flue gases and are collected through electrostatic precipitators as Fly Ash, while the heavier and coarser particles settle down at the bottom of the furnace and are known as Coal Bottom Ash.

V. TESTING PROGRAM

1. Compressive Strength Test: The compressive strength test is used to determine the ability of hardened concrete to withstand axial loads without failure. First, concrete specimens—usually cubes or cylinders—are cast and properly cured for a specified period, typically 7, 14, or 28 days, to achieve the required hydration and strength development. They are then placed in a compression testing machinewith the load applied gradually and uniformly along the longitudinal axis of the specimen. The load is increased steadily until the concrete specimen fails, which is usually indicated by cracking or crushing.

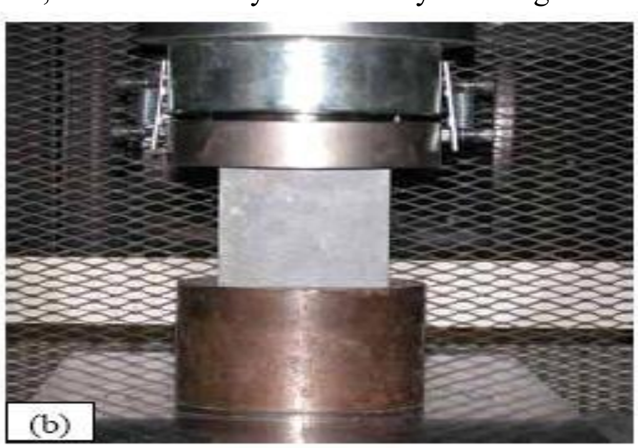
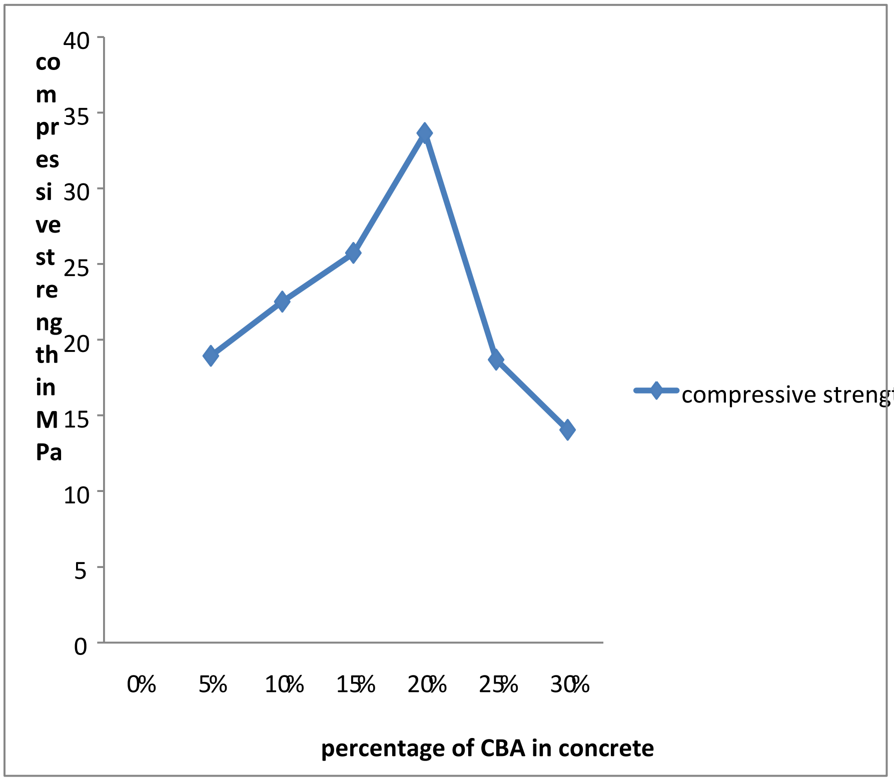


Table 1: Compressive test (for 28days)

Concrete variations	Average Mass density	Average comp.strength
Normal concrete	2767.30	29.76
Coal bottom ash 5%	2722.96	18.92
coal bottom ash 10%	2708.15	22.506
coal bottom ash 15%	2657.56	25.71
coal bottom ash 20 %	2617.04	33.644
coal bottom ash 25%	2593.33	18.68
coal bottom ash 30%	2577.44	14.04



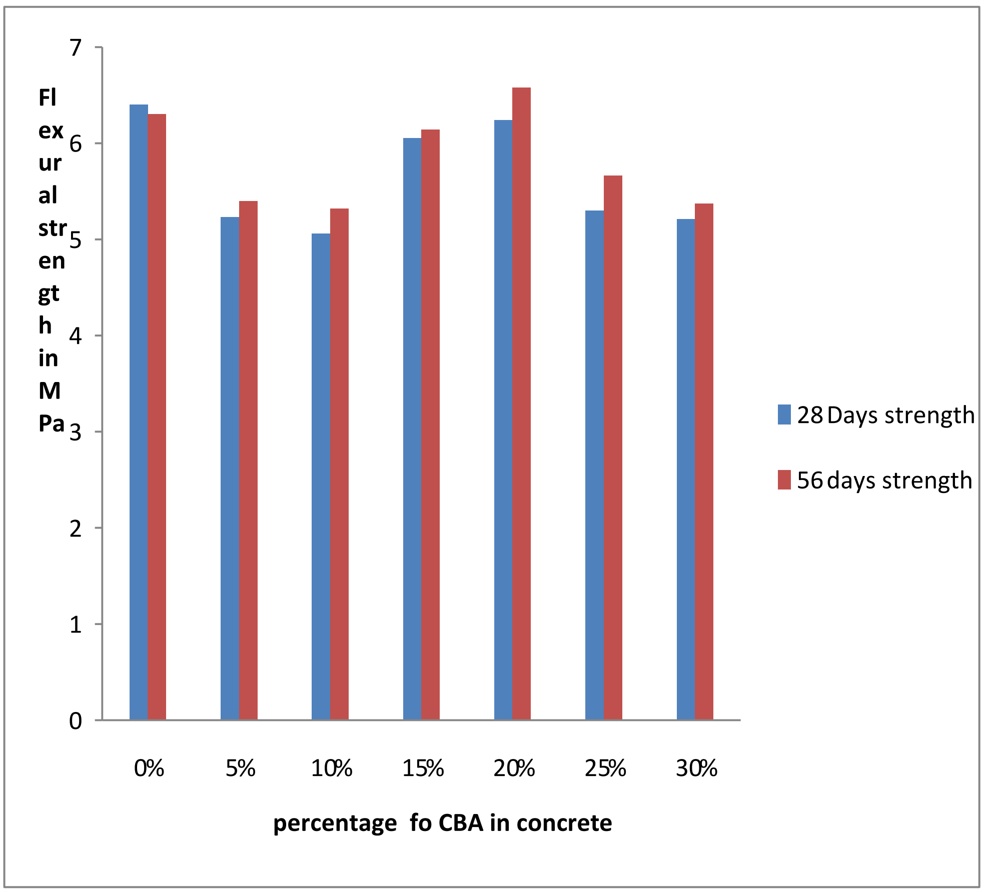
Graph 1: 28 days compressive strength

2. Flexural Strength Test: The beams were tested in flexural in accordance with the test procedure given in the Indian standards IS-516-1959, method of testing for strength of concrete- determination pf the flexural strength of concrete specimen. The standard size of beam specimen of 150mm×150mm×700mm.Over a span of 600mm, if nominal size of aggregate does not exceed 20mm, then 100mm×100mm×500mm specimen is used. Specimen is loaded at the rate of 4 kN/min for 150mm specimen and 1.8 kN/min for 100mm specimen. Maximum load at failure is noted.

International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696 Website: ijiert.org
Volume 13, Issue 6, June – 2026

Table 2. Flexural test results

Concrete variations	28 days strength	56 days strength
Normal concrete	6.24	6.30
Coal bottom ash 5%	5.23	5.40
coal bottom ash 10%	5.06	5.32
coal bottom ash 15%	6.05	6.14
coal bottom ash 20 %	6.40	6.58
coal bottom ash 25%	5.30	5.66
coal bottom ash 30%	5.21	5.37

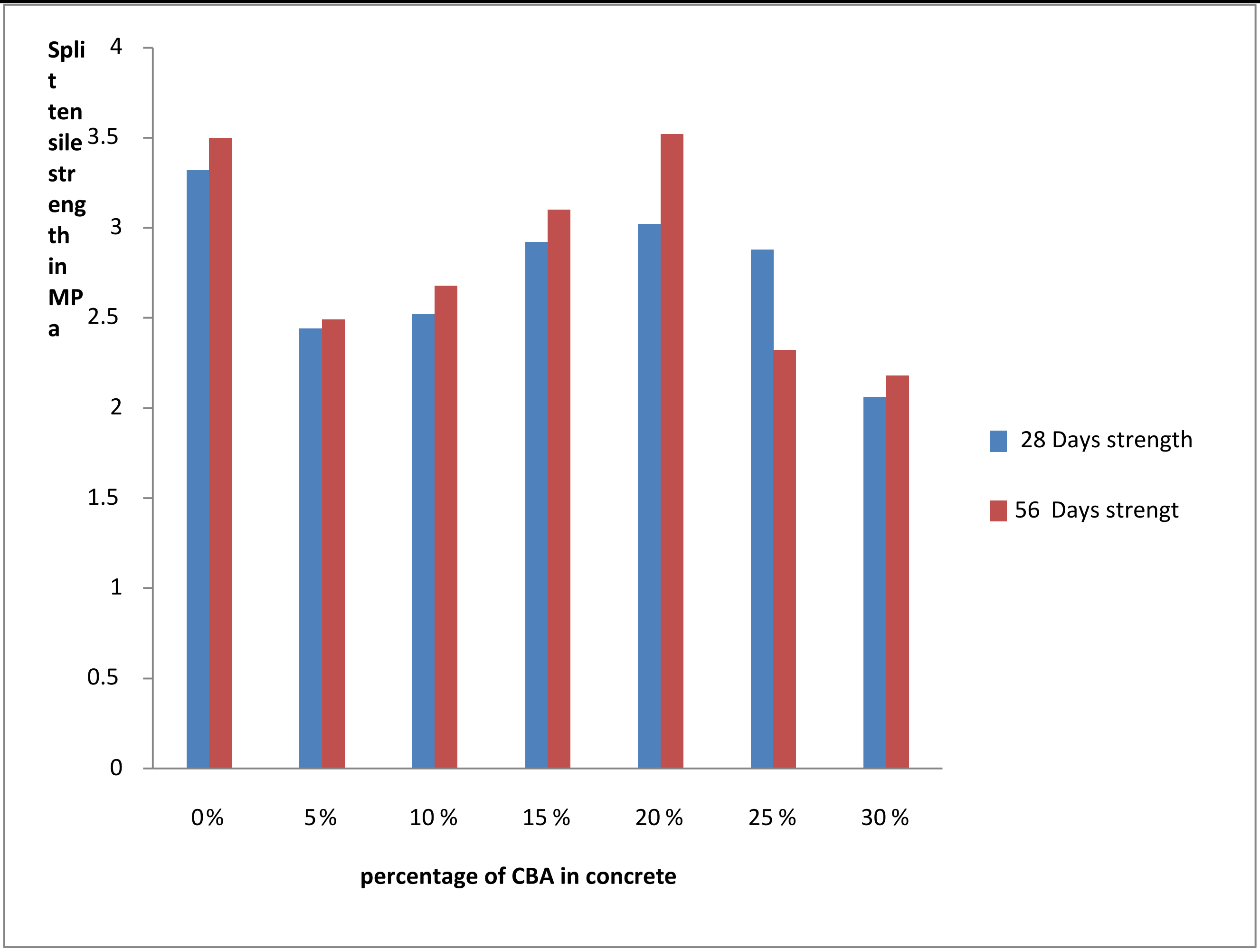


Graph 2: Flexural strength test results

3. Split Tensile Strength: The cylinder were tested for indirect tensile strength in accordance with the test procedure given in the Indian standards IS – 5816- 1970, method of testing for splitting tensile strength of concrete cylinder. The load is applied at the rate of 1.2 N/min-2.4 N/min and continuous untiled the specimen fail the maximum load is recorded.

Table 3: Split tensile test results

Concrete variations	28 days strength	56 days strength
Normal concrete	3.02	3.15
Coal bottom ash 5%	2.44	2.49
coal bottom ash 10%	2.52	2.68
coal bottom ash 15%	2.92	3.10
coal bottom ash 20 %	3.32	3.52
coal bottom ash 25%	2.88	2.32
coal bottom ash 30%	2.06	2.18



Graph 3: Split tensile

VI. CONCLUSIONS

1. The compressive strength of concrete increased with increase in replacement percentage up to the optimum level and decreased beyond that percentage. The concrete mix containing 20% Coal Bottom Ash and optimum GGBS replacement exhibited the highest compressive strength among all mixes.
2. At 7 days curing, the early-age compressive strength of modified concrete was slightly lower compared to conventional concrete because of the slower pozzolanic reaction of GGBS and Coal Bottom Ash.
3. The 28 days and 56 days compressive strength values showed significant improvement due to secondary hydration and formation of additional calcium silicate hydrate (C-S-H) gel. This indicates that GGBS contributes effectively to long-term strength development.
4. The maximum compressive strength obtained at 56 days was higher than conventional concrete for optimum replacement levels, indicating improved later-age performance of GGBS-CBA concrete.
5. The split tensile strength of concrete improved at moderate replacement levels of GGBS and Coal Bottom Ash. The increase in tensile strength indicates better bonding between aggregate particles and cement matrix.

6. The flexural strength of concrete beams also improved up to optimum replacement levels. This improvement may be attributed to denser microstructure and better particle packing in concrete containing GGBS and Coal Bottom Ash.

VII. ACKNOWLEDGEMENT

Experimental work was carried out using the facilities in Civil Engineering Department laboratory of DVVPCOE ,Ahilyanagar. I wish to thank Prof. A.A. Sengupta, my guide for their valuable Suggestions and authorities for their kind support. I also wish to thank the laboratory staff for their help and support during experimental work.

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