Int. J. Sci. R. Tech., 2025 2(4)
A Multidisciplinary peer-reviewed Journal
www.ijsrtjournal.com [ISSN: 2394-7063]

Original Article

Comprehensive Study of Partial Replacement of Cement with Biochar in Concrete

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ABSTRACT

Concrete is the most extensively used construction material in the world. Among the constituents of concrete (cement, coarse aggregate, fine aggregate) cement is the most expensive one. The production process of cement leads to generation of CO2. It is estimated that nearly 8% of global CO2 is generated during the production of cement. The objective of this study is to find the suitable replaceable material instead of cement. In this study biochar is used as a material for partially replace the cement. Biochar is a type of charcoal produced from biomass through a process called pyrolysis which involves burning of organic material in absence or limited supply of oxygen. Cement is replaced with biochar at 1%, 3%, 5%, 7%, 9%, 11%, and 13% by the weight of the cement. Slump tests as well as compressive strength test are performed on fresh and hardened concrete after curing period of 7 and 28 days. The results are then compared with conventional concrete (at 0% replacement) to determine the best combination of replacement of the material. From the investigation it was observed that 5% of biochar is best suitable for replacement of cement in concrete mix.

Keywords: Partial Replacement, Cement, Biochar, Concrete

INTRODUCTION

The construction industry is a significant contributor to global carbon emissions, with cement production alone accounting for approximately 8% of the world's CO_2 emissions. In search of more sustainable building practices, the partial replacement of cement with alternative materials has attained considerable attention. One such promising material is biochar. It a carbon-rich product derived from the pyrolysis of organic materials. Biochar has a potential to use in the construction sector, specifically as a partial cement replacement. This study investigates the effects of partial replacement of cement with biochar at 1%, 3%, 5%, 7%, 9%, 11%, and 13% by weight of cement. The aim of this study is to observe the usefulness of biochar as a sustainable alternative of cement and to understand its impact on the mechanical and durability properties of concrete. Using biochar in concrete has the potential to reduce the carbon footprint of cement production and also it improves certain properties of concrete, such as thermal insulation, moisture regulation, and increases strength and durability, depending on the characteristics of the biochar used. The results from this study could pave the way for more eco-friendly construction practices, contributing to the reduction of greenhouse gas emissions and the promotion of sustainable construction. The comprehensive analysis provided aims to offer valuable insights into the practical application of biochar in concrete and its implications for future research and industry practices.

LITERATURE REVIEW:

Ali and Sarmah(2018) demonstrated that biochar prepared from waste biomass can be used to improve the flexural strength and splitting tensile strength of conventional concrete at certain mix designs. Pulp and paper mill sludge and rice husk biochar at 0.1% of total volume were found to be the most suitable replacement binder with respect to mechanical strength in concrete. They found that biochar has a potential to use where early age strength development is required for conventional concrete applications.

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Gupta and Kashani (2021) investigated the effect of biochar produced from unwashed waste peanut shell on early age physical properties of cementitious composites. The findings from the study demonstrated that addition of biochar can substantially influence fresh properties, hydration, and early-stage strength and shrinkage of cement and cement-fly ash-based building materials. Due to biochar's angular shape, fine size and water-absorbing features, addition of biochar up to 3 wt% dosage reduces workability of fresh mixtures that resulted in reduction of flow and increase in yield stress and plastic viscosity of fresh paste. due to the increased compactness, higher hydration and increase in density in biochar-mortar compared to control addition of 1 wt% and 3 wt% biochar enhance compressive strength at 1-day, 3-day and 7-day age by 18–20% compared to plain mortar. Combination of biochar (3% by weight of cement) and fly ash (20% by weight of cement) resulted in 19% improvement in 7-day strength compared to only fly ash (20 %) mortar.

S. Gupta et al.(2020) showed that biochar produced from wood waste at 500 °C has high surface area and carbon content due to escape of volatiles and formation of meso and micro-pores during pyrolysis. Due to high porosity and pore-volume, the produced biochar showed relatively high water absorption capacity, which influence densification and redistribution of moisture in the hardened concrete matrix. Finer particle size of biochar compared to cement led to filler effect and densify concrete matrix and aggregate-paste interface zone. Water absorption capacity of biochar contributed to redistribution of moisture leading to reduced water-cement ratio at initial stage and densification of paste around biochar particles due to release of moisture at hardened stage.

Gupta S. et al. (2019) investigates the influence of biochar and combination of biochar and fly ash on carbonate mineralization in cement-mortar through accelerated carbonation curing. The findings demonstrated that addition of biochar contributes to generation of more hydration products and improves degree of hydration than control and it increases the products participating in carbonation reaction, leading to higher carbonate mineralization and CO_2 uptake. Higher initial moisture loss and carbonation negatively affects 7-day compressive strength of biochar mortar. However, due to increase of carbonate mineralization after 28 days in biochar-mortar compared to control leads to improvement in compressive strength. Adding biochar to fly ash mortar reduces rate of water ingress. Hence, enhance the durability of concrete constructions.

Zhao et al. (2018) incorporated different percentages of biochar in vegetation concrete to study the trend in porosity, permeability and compatibility of plants. They obtained that there is slight increase in the compressive strength of concrete in comparison to the mixture without biochar.

Sirico A. et al. (2021) conducted test on biochar obtained from wood waste to use as an additive for structural concrete. They observed that the best improvement is obtained in 365 days of dry curing, and at 5% biochar addition, there is an increase of almost 30% strength with respect to plain concrete.

MATERIAL & METHODS:

MATERIALS:

Cement: Cement is a material that has cohesive and adhesive properties in the presence of water. Such cements are called hydraulic cements. These consist primarily of silicates and aluminates of lime obtained from limestone and clay. Portland Pozzolana Cement (PPC) was used in design mix. The properties of cement are in compliance with the Indian standard organization. The specific gravity of cement is 3.15. The cement initial and final setting time are obtained as 45 minutes and 5 hours 15 minutes respectively and Fineness of cement is obtained as 8.5 %.

Coarse Aggregate: Coarse aggregates are materials passing through an IS sieve that is less than 75mm gauge and retain on 4.75 mm IS sieve. The shape and texture of aggregate affects the properties of fresh concrete more than hardened concrete. Concrete is more workable when smooth and rounded aggregate is used is used instead of angular or elongated particle suspension. The fine aggregate we used falls under zone- III (As per IS: 383:1970) and the specific gravity of fine aggregate obtained was 2.625.

Biochar: Biochar is produced by heating organic material or biomass in a controlled environment in absence or limited supply of oxygen. The process is known as pyrolysis. Biochar is composed of cellulose, hemicelluloses, lignin, etc. depending upon the biomass used for biochar preparation and pyrolysis temperatures involved. There is near total decomposition of hemicelluloses and the partial decomposition of cellulose and lignin. Treatment beyond 650 °C decomposes almost all of the holocellulose. On the contrary, the temperatures required for decomposing lignin are several hundred degrees higher than that for holocellulose (Kumar, A., & Bhattacharya, T. 2024) aggregate. The nominal size of aggregate we used is 20 mm (As per IS: 2386-1963). The specific gravity of coarse aggregate is 2.60.

Fine Aggregate: Fine Aggregates are material passing through an IS sieve that is less than 4.75mm gauge. Fine aggregate form the filler matrix between the coarse aggregate. The most important function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also helps the cement paste to hold the coarse aggregate

Fig-1: Biochar

METHOD:

Concrete cubes of size 150 x150 x150 mm are used for casting. Cement is replaced with biochar at 1%, 3% 5%, 7%, 11%, and 13% in a mixture of M25 grade of concrete. Table shows the amount of cement, coarse aggregate, fine aggregate and water required for different % replacements. The replacement is done with respect to the weight of the cement. 6 No. of cubes of each type for M25 Grade are casted and kept for curing and compressive strength test was done per IS at 7& 28 days

Fig-2: Method involved (Mixing, Moulding, Curing, Testing)

Table-1: Amount of materials (kg/ m^3) required for different percentage of replacements

-% Replacement	Ratio (Cement: Biochar: CA: FA)	Cement	Biochar	Water	Coarse Aggregate	Fine Aggregate
1%	1: 0.01: 2.84: 1.58	395.13	3.99	191.58	1123.52	627.04
3%	1: 0.03: 2.90: 1.62	387.15	11.97	191.58	1121.85	626.11
5%	1: 0.05: 2.95: 1.65	379.17	19.96	191.58	1118.5	624.25
7%	1: 0.07: 3.0: 1.68	371.19	27.94	191.58	1115.15	622.377
9%	1: 0.09: 3.06: 1.71	363.2	35.92	191.58	1113.48	621.4
11%	1: 0.12: 3.12: 1.74	355.22	43.9	191.58	1110.13	619.57
13%	1: 0.15: 3.15: 1.78	347.24	51.89	191.58	1108.45	618.64

RESULT AND DISCUSSION

Slump Test:

The results from the slump test shows that workability properties of concrete decreases with increasing % of biochar in the mix. The table below shows the slump test value for various % of replacements.

Table- 2: Slump test value after replacing cement with biochar

Sl. no	Description (replacement Biochar)	Slump Value(mm)	Workability
1	After replacing 0% Biochar	60	Medium
2	After replacing 1% Biochar	58	Medium
3	After replacing 3% Biochar	55	Medium
4	After replacing 5% Biochar	53	Medium
5	After replacing 7% Biochar	50	Low
6	After replacing 9% Biochar	47	Low
7	After replacing 11% Biochar	45	Low
8	After replacing 13% Biochar	40	Low

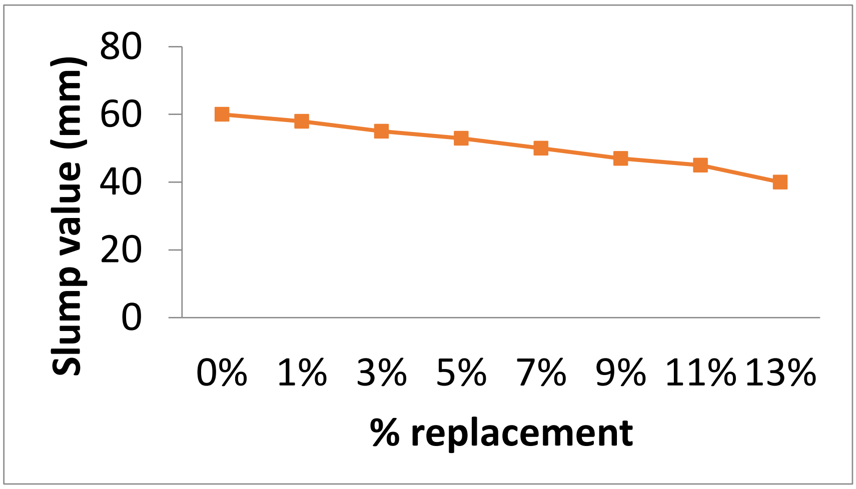

Fig- 3: Slump value v/s compressive strength

COMPRESSIVE STRENGTH:

The various types of cubes of different mixes were tested under compression testing machine (CTM) at 7 days & 28 days as recommended in IS code. The results obtained from all the experimental works carried under this study have been discussed below.

Comparision Of Compressive Strengths:

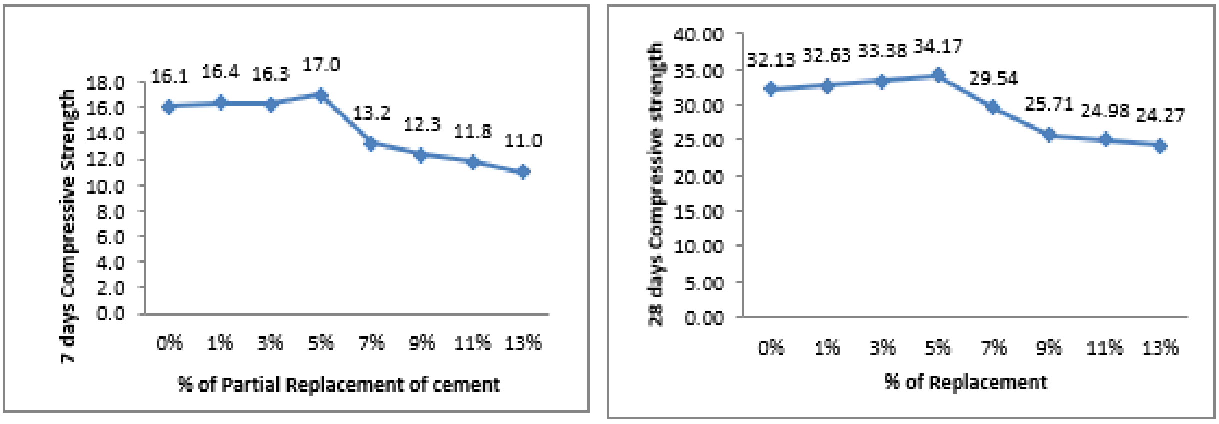

Fig- 4: Compressive strength at 7 and 28 days

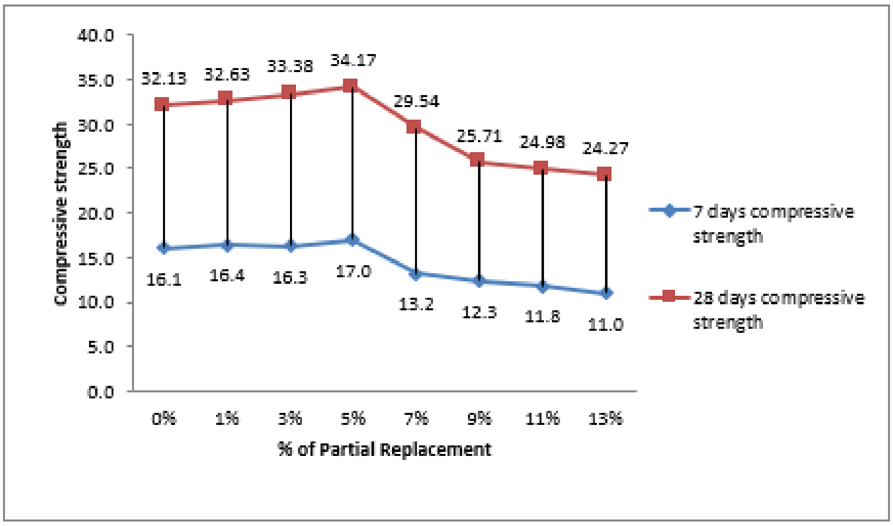

Fig- 5: Overall comparison of compressive strength at 7 and 28 day

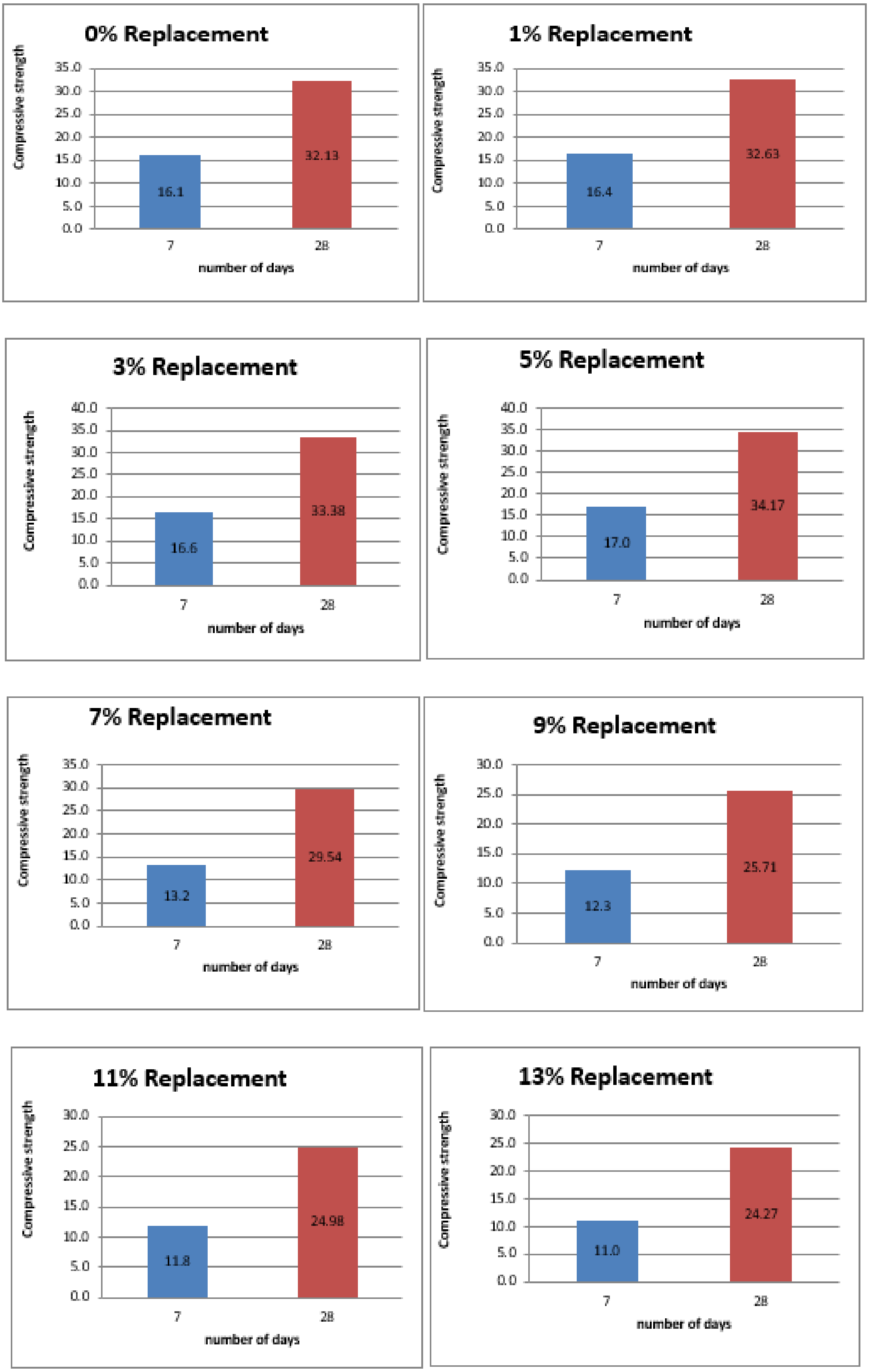

Fig- 6: Comparison of compressive strength of different % replacement of cement with biochar (standard M25 concrete) at 7 and 28 days

CONCLUSION:

The following conclusions can be made from the investigation:

i. The workability properties of concrete are decreasing with increasing percentage of biochar in the mix.
ii. The compressive strength of concrete cubes for all mix increases with age of concrete.
iii. The compressive strength of concrete cube is different for different proportions of biochar.
iv. From the investigation it is clear that 5% of biochar is best suitable for replacement of cement in concrete mix.
v. The compressive strength decreases drastically when 7% replacement of cement is done with biochar and further decreases with increase in percentage of biochar.

Porous structure of biochar allows to absorb and retain water which is then released gradually promoting cement hydration

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HOW TO CITE: Dr. Pranab Jyoti Barman*, Manash Pratim Deka, Ankita Gogoi, Gyandeep Das, Ritushna Sarmah, Manjit Pathak, Comprehensive Study of Partial Replacement of Cement with Biochar in Concrete, Int. J. Sci. R. Tech., 2025, 2 (4), 299-305. https://doi.org/10.5281/zenodo.15212106