

ENHANCING CONCRETE FLEXURAL STRENGTH: REPLACING CEMENT WITH FLY ASH AND BRICK KILN DUST

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Abstract

Concrete is now an essential building material for creation of any type of structural elements, including inflexible pavement as well as beams, columns, slabs, bridges, and girders. Cement is the most essential binding component in the manufacture of concrete because, when combined with water, it can bind both coarse aggregate and fine aggregate. The terms brick kiln dust and fly ash, which have certain binding qualities when mixed with water, are waste products, as indicated by the paper's title. The researcher's objective is to show how fly ash and brick kiln dust mixed in the percentages of 0%, 10%, 20%, 30%, and 40% are used to partially substitute ordinary portland cement of 43 grade during the production of M25 grade of concrete mix design and to calculate the flexural strength of plain cement concrete beam in accordance with indian standards. The outcome of this research analysis demonstrates that FA and BKD can be employed in the manufacturing of concrete with the objective of lowering both emissions of greenhouse gases and cement concrete production costs.

Keywords: Brick Kiln Dust, Concrete, Fly Ash, Flexural Strength, Ordinary Portland Cement 43 grade Cement

Introduction

People frequently confront the issue of emission of carbon dioxide (CO₂) during cement manufacture, which is the pollutant that is extremely harmful to the society and the environment. The major goal is to decrease the cement production because it emits 1.25 tonnes of CO₂ per tonne of cement production, contributing to the greenhouse effect. Besides

cement, other waste products like Fly Ash (FA) and Brick Kiln Dust (BKD) are also harmful to the environment and India is ranked as the second-largest brick producer after China (Mills, 2010). When brick is produced in large quantities, wastes like BKD are deposited on open spaces, leading to contamination of the groundwater owing to the fact

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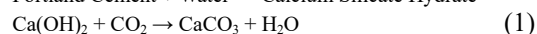
that the BKD contains many chemicals like lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) (Gupta *et al.*, 2019). Therefore, scientists and researchers have made considerable advancements in creating a diverse array of new supplementary cementitious materials (SCMs) as substitutes to partially supplant ordinary Portland cement (OPC) in concrete production. These SCMs, engineered as sustainable alternatives, engage in a pozzolanic reaction, rendering them suitable for varying cement replacement ratios. This practice effectively curtails energy usage, diminishes CO₂ emissions, and offers cost savings, thereby fostering the creation of environmentally friendly concrete (Hamada *et al.*, 2023). Additionally, we know that cement is the primary component used in the manufacturing of concrete, and in this study, we are able to produce concrete with the same mechanical properties using other waste materials generated (Yazici and Arel, 2012). The utilization of various waste materials during the production of concrete and also the physical characteristics of concrete, both have been extensively studied in the literature (Rana and Talwar, 2020), by repurposing waste generated from industrial and agricultural activities, it's possible to create new building materials. There's a wide array of these waste materials that can be effectively utilized in the production of concrete (Tay, 1990). Both FA and BKD, waste products from byproducts of coal combustion in power plants and brick kilns, are widely used to enhance the mechanical properties of concrete (Bashir, 2018). It has been observed that addition of BKD improves the cement mortar's strength and physical properties of concrete (Singh, 2018). It has been discovered that the additopn of Rice Husk Ash (RHA) with BKD generates the desired strength of concrete (Rather, 2018). Discovering the chemical attributes of materials stands as a pivotal phase in the creation of concrete. As these materials combine with water, they initiate specific chemical reactions that significantly influence the concrete's ultimate strength (Dubey *et al.*, 2022). Relying solely on chemical and physical characteristics doesn't yield the optimal outcomes for pozzolanic materials. A comprehensive understanding demands consideration of additional factors such as water-cement ratio, pozzolan type and quantity, cement variety, age of the mixture, as well as the use of water-reducing admixtures. An experimental program encompassing these elements becomes crucial for an accurate assessment (Aliu, 2023). When compared with other European countries, Germany demonstrates relatively higher water-to-cement ratios (w/c) and lower minimum cement content in certain typical exposure classes: XC1: 0.75 compared to 0.65, XC4: 0.60 versus 0.50,

XF1: 0.60 in contrast to 0.55, and XC3: 0.65 as opposed to 0.55 (Müller, 2023).BKD has been shown to be an effective method of making high quality cement concrete with appropriate workability and setting times (Singh and Bharosh, 2018). Several further researchers have observed the physical properties of concrete, curing time, design mix, and material considerations. OPC 43 grade cement is utilized in the current work as it is readily accessible in large quantities. However, in the future, conventional OPC of grade 53 may be used for the similar experimental work.

Chemical Properties of Materials

The primary conventional material needed for building infrastructure is the blend of cement, fine aggregate, coarse aggregate, and water, commonly referred to as concrete (Ashwini *et al.*, 2023). A major step in the production of concrete is determining the chemical properties of the components. When ingredients and water are combined, certain chemical reactions occur, and these processes also determine the concrete's strength (Khan *et al.*, 2018).

Portland Cement + Water → Calcium Silicate Hydrate



Pozzolana + Ca(OH)₂ + Water → C-H-S(Glue)

In Equation (1), when Portland cement and water reacts with each other, concrete gains early strength. Later on, when pozzolanic material is combined with lime (CaO) and water (H₂O), the early strength of concrete gets affected, but the addition of silica from brick kiln dust adds more strength to the concrete.

OPC 43 Grade

When lime and clay are calcined, cement is typically created as a grey, powdery binding substance. Concrete is the combination of produced substances like cement with coarse aggregate (CA), fine aggregate (FEA), and water. OPC 43 grade refers to cement with a compressive strength of 43 N/mm² after curing the specimen of size 70.6 mm for 28 days, according to the confirmation of Indian Standard (IS) 8112-2013 (Bureau of Indian Standards 8112 :2013). Blended cement, also known as Portland Pozzolana cement, is a new type of cement that is created when some pozzolanic elements, like fly ash, are used to replace some of the ordinary portland cement (OPC) of grade 43. The chemical ingredients of OPC 43 grade cement, as per IS 8112-2012, namely, alumina, silica, calcium, magnesia Iron, etc. have been experimentally determined and are presented in Table 1.

Table 1. Chemical Ingredients of Cement

Ingredients	Test Result
Loss of Ignition (%) by weight	3.10 %
Insoluble Residue	2.15 %
SiO ₂	19.20 %
Al ₂ O ₃	4.25 %
Fe ₂ O ₃	3.16 %
CaO	62.30 %
MgO % by weight	1.25 %
SO ₃ % by weight	2.20 %
Lime Saturation factor (LSF), CaO - 0.7 SO ₃	1.01 %
2.8 SiO ₂ + Al ₂ O ₃ + 0.65 Fe ₂ O ₃ Alumina to Iron Oxide ratio (%)	1.34 %

Table 3. Chemical Ingredients of Fly Ash

Ingredients	As per IS 3812 Part (1)-2013 (%)
SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃ (%) by weight	Maximum 70
SiO ₂ Present by weight	Minimum 35
Reactive Silica Present by Weight	20
MgO Present in Weight	Maximum 5
SO ₃ present by Weight	Maximum 3
Available Alkalis (Na ₂ O), Weight	Maximum 1.5
Total Chloride present by Weight	Maximum 0.05
Total Loss of Ignition (LOI), by Weight	Maximum 5

Brick Kiln Dust (BKD)

BKD is often a waste material with a light red color that is obtained from brick kiln factories. Nowadays, there is a lot of building work being done, which increases the need for brick and leads to waste like BKD being produced. Typically, it consists of dust particles made up of ash (wood and coal) and (soil and sand). Because alkali is a component of BKD, there is an equal amount of reactive material in BKD. The chemical constituents of brick kiln dust, as outlined in (Uddin, 2004), such as alumina, silica, calcium, magnesia, iron, etc., have been experimentally determined and are presented in Table 2.

Table 2. Chemical Ingredients of BKD

Ingredients	Test Result (%)
SiO ₂	67.43
Loss of Ignition	1.1
Fe ₂ O ₃	7.99
Al ₂ O ₃	1.99
CaO	2.12
MgO	2.46
SO ₃	0.39
Na ₂ O	0.08
K ₂ O	0.25
Other	7.9

Aggregates

According to IS 2386 (Part 1) -1963, Indian Standard 383 -1970, and IS 460 -1962, coarse aggregate with a size of 20 (mm) and 10 (mm) and fine aggregate with a sieve size of less than 4.75 (mm) are utilized in construction (Passed through 4.75 mm and retained on to 75 micron). The results are based on the laboratory test that was conducted.

Materials and their Physical Characteristics

OPC 43 Grade: Some tests have been carried out in accordance with IS 8112 (1989), IS 4031 (Part 1) (1996), IS 4031 (Part 4) (1988), IS 4031 (Part 5) (1988), and IS 4031 (Part 6) (1988), and their results are shown in Table 4

Table 4. Physical Characteristics of Cement

Name of the Test	Test Result	According to Indian Standard
Fineness	Obtained 9% residue	< 10%
Modulus (FM)	31%	Penetrating depth (5 to 7 mm)
Consistency Test	(5.4 mm)	
Initial Setting Time (T)	80 minutes	T > 30 minutes
Final Setting Time	325 minutes	T < 600 minutes
Compressive Strength	44 N/mm ²	43 N/mm ²
Specific Gravity(G)	3.15	3.11- 3.16

Fly Ash (FA)

According to IS 3812 (Part 1) -2013 (Bureau of Indian Standards IS 3812: 1.2013), FA is a finely wasted residue that is released during the combustion of bituminous or sub-bituminous coal to produce electricity. Fly ash is a waste product that is produced in vast quantities and is now used in many different constructions works. The chemical ingredients of FA, as per IS 3812:1.2013, are experimentally determined and presented in Table 3.

Coarse Aggregate: Some tests have been conducted in accordance with IS 383 (1970), IS 2386 (Part 1) (1963), IS 2386 (Part 2) (1963), IS 2386 (Part 3) (1963), IS 2386 (Part 4) (1963), IS 2386 (Part 5) (1963), and IS 460 (1962), and the results are shown in Table 5.

Table 5. Physical Characteristics of Coarse Aggregate

Name of the Test	Test Result	According to Indian Standard
FM	5.24	For all in aggregates 3.5 to 6.5
Flakiness Index (FI)	15.10%	Up to 35%
Crushing Value Test	18.25%	Up to 45% for concrete and 30% for Highways.
Impact Value Test	11.45%	Up to 45% for concrete and 30% for Highways.
G	2.65	2.5 to 3.0
Water Absorption	0.49%	Not more than 0.6% per unit weight

Fine Aggregate: Some tests have been conducted in accordance with IS 383 (1970), IS 2386 (Part 1) (1963), IS 2386 (Part 2) (1963), IS 2386 (Part 3) (1963), IS 2386 (Part 4) (1963), IS 2386 (Part 5) (1963), and IS 460 (1962), and the results are shown in Table 6.

Table 6. Physical Characteristics of Fine Aggregate

Name of the Test	Test Result	According to Indian Standard
FM	2.31	2.2 -3.2
Dry Density (ρ)	1.65g/cm ³	1.49 to 1.6965g/cm ³
G	2.59	2.65
Optimum moisture content (OMC)	12.64%	11-15%

Brick Kiln Dust (BKD): The physical properties of brick kiln dust, as outlined in (Uddin, 2004), have been experimentally determined and are presented in Table 7.

Table 7. Physical Characteristics of BKD

Name of the Test	Test Result
FM	1.99
ρ	1.42 g/cm ³
OMC	13.81%
G	2.35

Fly Ash (FA): Different tests have been carried out in accordance with IS 3812 (Part1)-2013 and from journal research, as shown in Table 8.

Table 8. Physical Characteristics of Fly Ash

Name of the Test	Test Result	According to Indian Standard
FM	1.76	FM < 2
ρ	1.19 g/cm ³	1.01 to 1.78 g/cm ³
OMC	20.34%	Max. of 11 to 53%
G	2.18	2.1-3.0

Methodology

In this research work, partial replacement of cement with waste materials like BKD and FA is done to obtain the flexural strength of Plain cement concrete beam (PCCB) of M25 design mix concrete. The size of the beam used for determining the flexural strength is 700 mm x150 mm x150 mm. In this research area five cases have been performed to achieve the flexural strength of M25 design mix concrete. The order of replacing the cement is as (0% BKD+0%FA), (5% BKD+5%FA), (10% BKD+10%FA), (15% BKD+15%FA), & (20% BKD+20%FA). The cement is partially replaced in the order of 0%, 10%, 20%, 30% and 40% by weight, with respect to the combination of BKD and FA. To attain the flexural strength, the target mean strength is also used. Clause No. 6.2.2 of IS 456-2000, the value of characteristic compressive strength of a different design mix and standard deviation is given in the Table 8 of IS 456-2000 (Bureau of Indian Standards IS 456 :2000). Concrete mix design the grade M25 has been carried out following the stipulation as mentioned in IS 456-2000 and IS 10262-2019. Beam specimens are casted as per IS 516-2019 and tested after 28 days of curing.

Note: According to Indian standards, the FA and BKD waste materials' particle size must be like that of cement.

The flexural strength, as per IS 456-2000 for mix design of M25 grade concrete, is obtained by using the formula:

$$(f_{cr}) = 0.7\sqrt{f_{ck}}N/mm^2 \quad (2)$$

In above equation (2), f_{ck} is the characteristic compressive strength of concrete

Now,

$$\text{Target mean strength } (f'_{ck}) = f_{ck} + 1.65S \quad (3)$$

“S” is the Standard Deviation as per IS 10262-2019 (Bureau of Indian Standards IS 10262: 2019) and for M25 the value of S = 4.0 N/mm².

Therefore,

$$(f'_{ck}) = (25 + 1.65 \times 4.0) = 31.6 \text{ N/mm}^2 \quad (4)$$

Put the above value in equation (2) We get,

$$\begin{aligned} \text{Flexural strength } (f_{cr}) &= 0.7\sqrt{31.6 \text{ N/mm}^2} \\ \text{Flexural strength } (f_{cr}) &= 3.93 \text{ N/mm}^2 \end{aligned} \quad (5)$$

This is the flexural strength which must be obtained for M25 grade of Design Mix after 28 days of curing and their design mix specification is displayed in Table 9.

Table 9. Shows specification of design mix

Specifications	Values/ Details
Grade of Cement	OPC 43
Maximal aggregate size	20mm
Minimal content of Cement	300 kg/m ³
Maximal ratio of Water/Cement	0.50
Slump	50-100mm
Exposure Condition	Moderate (RCC)
Method of Placing	Manual
Maximal Cement Content	450 kg/m ³
Chemical Admixtures	None
Mineral Admixture	Fly Ash

Table 10 displays many parameters that is related to the materials utilized in this experiment. FA and BKD are used in CASE I to partially replace the cement (0%). In CASE II, FA and BKD are blended to replace 10% of cement with 5% each. In CASE III, FA and BKD are blended to replace 20% of the cement with 10% each. In CASE IV, FA and BKD are blended to replace 30% of cement with 15% each. In CASE V, FA and BKD are blended to replace 40% of cement with 20% each.

Table 10. Shows values calculated from the material data

Ingredients (kg)	CASE I	CASE II	CASE III	CASE IV	CASE V
OPC-43	394	354.6	315.2	275.8	236.4
FEA	754	754	754	754	754
CA	1103	1103	1103	1103	1103
FA	0	19.7	39.4	59.1	78.8
BKD	0	19.7	39.4	59.1	78.8
Water Content	197	197	197	197	197
W/C	0.5	0.5	0.5	0.5	0.5

Figures 1, 2, and 3 display the 75 mm slump is acquired when the water to cement ratio is 0.50. According to IS 456-2000, clause no. 7.1, this degree of workability is preferred for the construction of structural components, including beams, columns, slabs, and foundations.



Figure 1. Materials Before Mixing



Figure 2. Mixing of Materials



Figure 3. Slump Test

Results and Discussion

According to IS 516-1959 (Bureau of Indian Standards IS 516: 1959), the beam must be in a moist state when the weight is measured, and the compression process starts. The data represents the direct replacement sequence of the cases and flexural strength with respect to curing time are shown in Table 11. The flexural strength of the beam specimen of dimension 700 x 150 x 150 (mm) are calculated using the equation no. (6). Figures 4, 5, 6, 7 and 8 represents the various stages of a Plain Cement Concrete Beam (PCCB) before and after its failure.

Table 11. Flexural Strength with respect to curing days

M25	f_{cr} at 7 days (N/mm ²)	f_{cr} at 14 days (N/mm ²)	f_{cr} at 28 days (N/mm ²)
CASE I	3.9	4.2	4.4
CASE II	3.7	4.1	4.2
CASE III	2.8	3.3	4.1
CASE IV	2.5	3.2	3.98
CASE V	2.2	3	3.6

Conclusions

In this research work the beam specimens are cured for 28 days for which the results for different cases from Case I to Case V have been found, such as for CASE I, the flexural strength is obtained as 4.4 N/mm². Likewise, for the CASE II, CASE III, CASE IV and CASE V, the concrete compressive strengths were obtained as 4.2 N/mm², 4.1 N/mm², 3.98 N/mm² and 3.6 N/mm², respectively. However, as per design mix, the target mean strength of M25 design mix concrete is 31.6 N/mm² and on the basis of target mean strength the Flexural strength obtained as per calculation done in equation (v) is 3.93 N/mm². Therefore, from the above readings, it has been observed from the CASE IV that if the cement is substituted by 30% (with 15% of FA and 15% of BKD combined), as, shown in Figure 9, the concrete gives the promising flexural strength when it is compared with the flexural strength, stipulated in IS 456-2000.

FA and BKD are waste products which can be used as a partial cement replacement in concrete production. The physical property of concrete is an important parameter which indicates the quality of concrete. Here, in this research work, an

investigation of the two input materials, FA and BKD on the flexural strength of plain cement concrete beam has been carried out. In both the material FA and BKD, silica is the major chemical component. It is established that the function of silica during concrete production is to increase the strength of concrete. From the above readings it has been found that up to 30% replacement of cement with FA (15%) and BKD (15%) produces more flexural strength, whereas above 30% replacement that it is further observed that the flexural strength is decreasing due to increase in the above two inputs FA and BKD. The decrease in flexural strength is due to increase in silica content as excessive silica swells the hygroscopic gel and increases the volume of concrete resulting to the loss of strength.

It may be concluded, the use of FA and BKD up to a certain percentage in the production of concrete seems to be a viable waste product that would enhance the physical properties of concrete which in turn reduces the consumption of cement.

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Compliance with Ethical Standards: The work was completed in its entirety in accordance with Indian standards. There is no piracy in the study effort; in fact, some information has been gathered to enhance my research, and the specifics of those data are cited in the footnotes.

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Conflict of Interest Statement: The authors affirm that they have no known financial or interpersonal conflicts that might have looked to have influenced the research presented in this study.

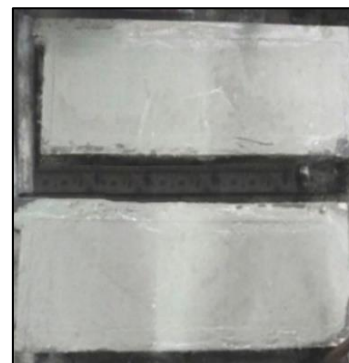


Figure 4. Casting of PCCB

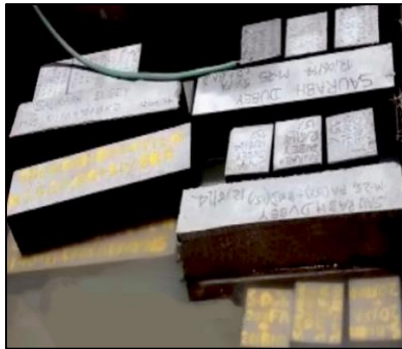


Figure 5. Curing of PCCB



Figure 7. Testing of PCCB



Figure 6. Centering of PCCB



Figure 8. Failure of PCCB

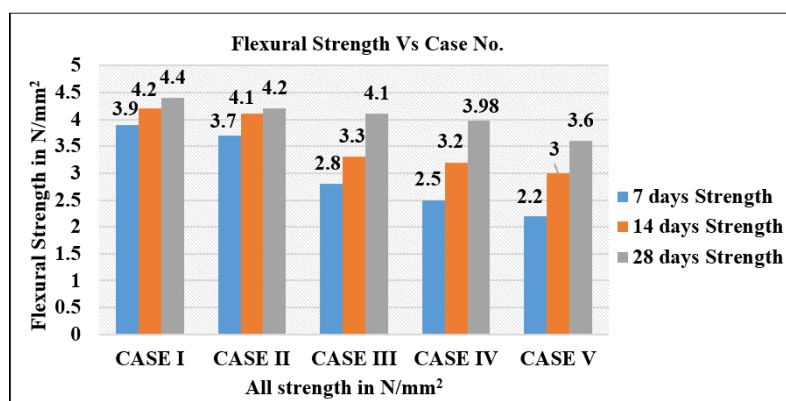


Figure 9. Column histogram demonstrating flexural strength of PCCB to various cases

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