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IMPACT OF ECO FRIENDLY BLAST FURNACE SLAG ON PRODUCTION OF BUILDING BLOCKS

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ABSTRACT

Solid waste management is one of the prime concerns in the world due to ever increasing proportion of non-biodegradable industrial waste product. Blast Furnace Slag (BFS) is one of the largest by products of steel and iron industries which creates scarcity of land filling area due to ineffective reuse and recycle. The use of such substance to create building blocks not most effective makes it economical, however it also enables in decreasing disposal concern. Clay bricks are the oldest walling material of construction industries. Due to preferable mechanical properties bricks are considered as prime source of masonry units that is used as walling material. Conventional clay bricks required burning process known as kiln firing which emits huge amount of CO_2 into the atmosphere. World is facing same problem with the production of cement too. The major reasons behind pollution and environment depletion are due to unremitting decay in natural resources caused form deriving of raw materials such as sand, clay and dirt and also from huge amount of hazardous and non-hazardous wastes produced by the industries. Reuse of industrial waste such as BFS instead of naturally occurring raw material leads to contribute towards green environment. Present study intended toward use of steel and iron industry waste for manufacturing of building blocks to promote low cost housing along with mitigation of environmental violation. Based on the results, BFS may effectively replace with naturally occurring fine aggregates due to favourable physical properties. Durability aspects in terms of water absorption and compressive strength also found adequate as per the requirement of IS codes. An amount of partial to full replacement of BFS may allow as per required weathering conditions.

KEYWORDS

Industrial waste, walling material, Building blocks, Brick, Blast furnace slag

INTRODUCTION

Approximately 500 kg per tonne waste materials are generated from crude steel by steel plants. Out of these wastes, around 400 kg per tonne is only BFS [1]. India's crude steel production for 2018 was 106.5 Mt, up by 4.9% in 2017, meaning India has replaced Japan as the world's second largest steel producing country [1].

The most widely recognized walling material utilized in structure development is bricks. Bricks are the simplest and oldest building blocks used in construction. Annual production of bricks is currently 1391 billion units worldwide and the demand expected to be rising [3]. In India the annual demand is 200 billion bricks, producing around 250 billion bricks from 1, 50,000 kilns [2, 4]. The main ingredients used for bricks are derived from natural resources occupies more than 80% by volume. The traditional method consumes 350 million tonnes of fertile soil and 25 million tonnes of coal annually [2]. On the other hand manufacturing of cement along with its use also tends to increase the amount of CO_2. The huge consumption of naturally occurring materials and energy eventually lead to exhaustion of environment.

In both developed and developing countries, the problem of waste management has already become an issue to be addressed immediately. This problem is compounded by the rapidly increasing amounts of industrial wastes of a complex nature and composition.

As per the review of previous research works, various variety of wastes have been utilized by the researchers in terms of developing building blocks. Table 1 shows a summary of research work done for production of building blocks/bricks from various industrial wastes. But the effective percentage of industrial waste utilization was quite inadequate due to unfavourable mechanical and chemical properties.

Tab.1 - Production of building blocks/bricks from various industrial wastes

S. No.	Waste material used	Outcomes	Reference No.
1	Paper mill sludge (PMS)	An optimum replacement of PMS at 10 % shows better results. With laterite soil the compressive strength at 850^{0}c temperature was found around 9 MPa increased up to 11MPa at temperature 900^{0}c.	[3]
2	Granite fines	Mardini blocks with granite fines show an increase of 120% in compressive strength as compare to conventional soil blocks. Also adobe blocks with granite fines show135% more compressive strength as compare to conventional soil blocks.	[4]
3	Fly ash and quarry dust	Cement, fly ash, quarry dust taken 70%, 20%, 10% respectively, for manufacturing brick and it was observed that compressive strength of bricks was found 13.5 MPa relevant to normal bricks 14.0 MPa after 21 days curing.	[5]
4	Brick debris and quarry dust	Re bricks were found adequate in compressive strength 7.352 MPa at an optimum replacement of 20% as compare to fly ash brick 7-12 MPa and IInd class clay brick with strength more than 7 MPa.	[6]
5	Fly ash ,lime and gypsum	Fal-G Bricks with mix proportion of 60% fly ash, 15% lime, 15% gypsum and 10% sand shows better compressive strength 5.34 MPa as compare to clay bricks 3.98 MPa.	[7]
6	Rice husk (0 to 5%) by weight	Higher compressive strength obtained at 2% replacement of rice husk.	[8]

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7	Waste marble powder 0% to 80% by weight	Found relative water absorption and mechanical properties up to 10% replacement.	[9]

Keeping the views of previous research works, present study makes an effort to extricate the problem of managing steel industrial waste like BFS by its effective utilization to turn it into valuable building blocks as per required durability and mechanical properties ultimately leads to promote sustainable and low cost development and also to mitigate the depletion of natural resources.

MATERIALS AND METHOD

BFS was collected from the furnace workshop of Iron Industry located near Gadbadi Puliya, AB Road, Indore, M.P., India. More than 20 steel and iron industries are working at present in Indore and also producing a huge amount of wastes every day. Characteristics of raw materials have been carried out considering procedure and requirements as described in IS Codes. In order to determine specific gravity, water absorption, silt content and unit weight of BFS and river sand, 1.18mm passing and 150µm retained particles were selected. The properties of BFS and river sand are showed in Table 2 and Table 3 respectively. Similarly, to determine properties of PPC cement the particle size were chosen it was finer than 90µm. Table 4 shows the properties of PPC cement.

Tab. 2 - Physical properties of BFS

Properties	Value	Procedure
Specific Gravity	3.2	As per IS 2386-Part- I and III:1963 [10,11]
Unit weight (kg/m^3)	1800	
Water Absorption	0.4%	
Silt Content	1%	

Tab. 3 - Physical properties of river sand

Properties	Value	Requirements as per IS 383:2016 [12] and IS 2386- Part- I and III:1963 [10,11]
Specific Gravity	2.6	2.5-3.0
Unit Weight (kg/m^3)	1560	-
Water Absorption	1.4%	Less than 2%
Silt content	3%	Less than 5%
Fineness Modulus	2.8	2.0-3.5

Tab. 4 - Physical properties of PPC cement

Properties	Value	Permissible values	Requirement
Unit Weight (kg/m^3)	1310	-	-
Standard Consistence	27%	25-35%	IS 4031- Part-IV and V:1988 [13,14]
Initial Setting Time	33 Minutes	Minimum 30 Minutes	
Final Setting Time	550 Minutes	Less than 600 Minutes	

BFS comprises the required properties that are useful to convert it into building materials. The physical property of BFS lies between required limits which show its adequacy.

EXPERIMENTAL PROGRAMME

Procedure for BFS based building block production

Crushed sample of BFS was replaced in different amount (10%, 20%, - - -, 100%) by volume of sand and a standard amount of 10% cement was added. The control building block specimens were also prepared (0% BFS) to set the benchmark for results. 40–45% of water was added to dry mix to convert it into the shape of building blocks. Brick hand moulds of size 19cmX9cmX9cm were used for casting building blocks. For initial removal of moisture brick specimens were air-dried at room temperature for 24 h and then placed into curing tank after stripping. The building block samples were designated as B represented the identity of BFS. Table 5 shows the composition of different mixes for preparing building blocks. Total 60 numbers of moulds were prepared to ensure the properties of building blocks.

Tab. 5 - Composition of different mixes

S. No.	Specimen	Proportion (by volume) C%-S%-SL%
1	B-0	10%-90%-00%
2	B-10	10%-80%-10%
3	B-20	10%-70%-20%
4	B-30	10%-60%-30%
5	B-40	10%-50%-40%
6	B-50	10%-40%-50%
7	B-60	10%-30%-60%
8	B-70	10%-20%-70%
9	B-80	10%-10%-80%
10	B-90	10%-00%-90%
C- Cement, S- Sand, SL- Slag		

Determination of properties of building blocks

Water absorption of prepared building blocks was determined as per the procedure described in IS-3495 (Part-III):1992 [15]. Compressive strength of building blocks was determined with digital compression testing machine (CTM 2000kN capacity) as per IS-3495 (Part-I):1992 [16]. Both tests were performed after 28 days curing. (Figure 1) shows BFS based building blocks after 28 days curing.

Fig.1- BFS based building blocks after 28 days curing

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METHODOLOGY

The purpose of this research is to develop building blocks using BFS and to conduct experimental investigations demonstrating efficacy of the product. Method implying experimental work followed in this research is showed in (Figure 2).

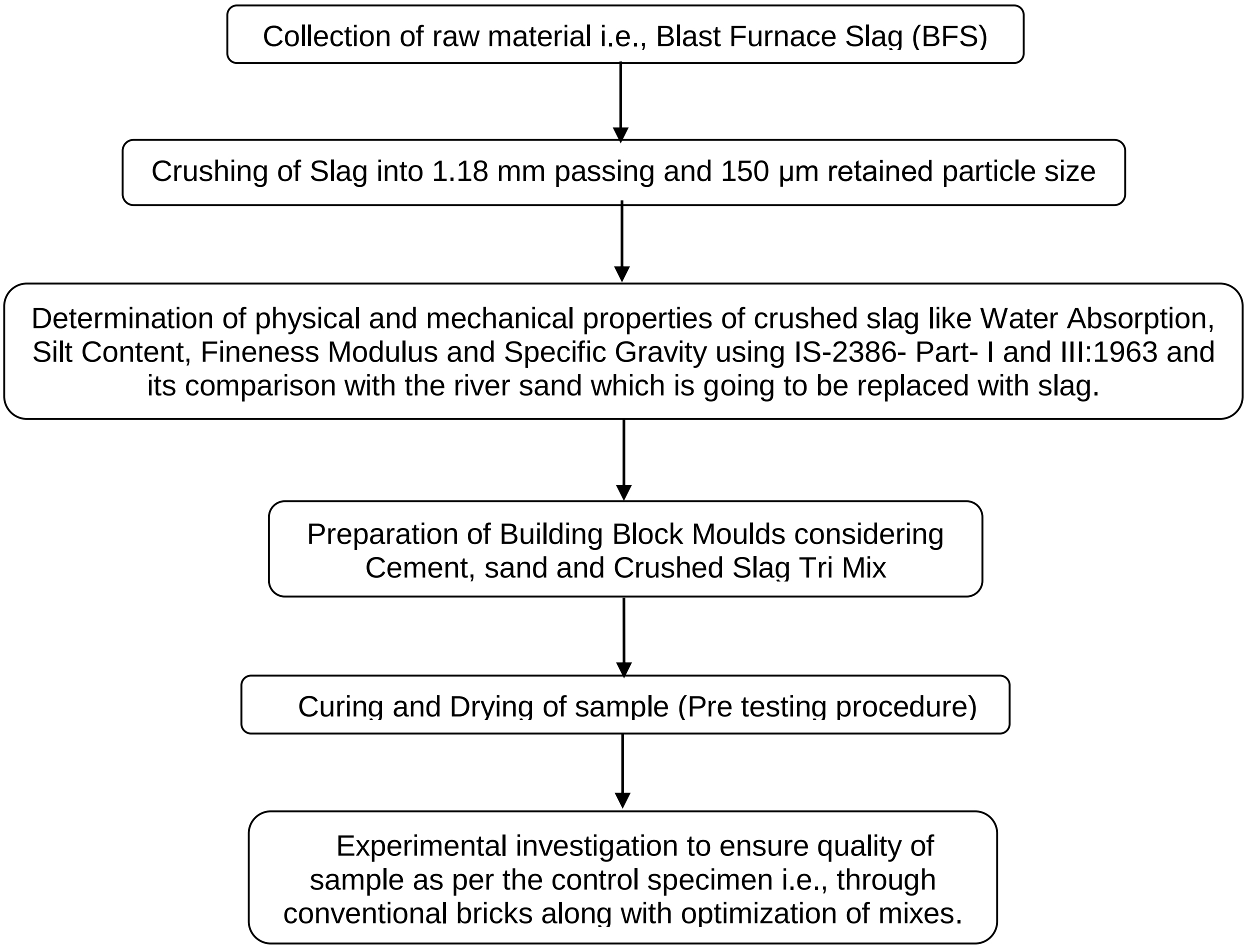

Fig. 2 -Methodology

RESULTS AND DISCUSSION

Determination of compressive strength

Compression test was carried out when building blocks acquired the necessary curing condition i.e., after 28 days curing and in wet condition. Table 6 shows the observations found during experimental investigation.

Tab. 6 - Compressive strength of building blocks

S.No.	Specimen	Average Compressive Strength (MPa)
1	B-0	7.25
2	B-10	5.85
3	B-20	6.40
4	B-30	6.65
5	B-40	7.10
6	B-50	5.45
7	B-60	5.25
8	B-70	4.90
9	B-80	5.60
10	B-90	4.50

Determination of water absorption

Water absorption test was carried out on completely dried samples. Initially blocks were dried using ventilated oven by maintaining temperature to 110ºC. After drying, the blocks were immersed in clean water at a room temperature of 27 ± 2 °C for 24 hours. After 24 hours immersion the blocks were removed and wipe out using damp cloth. Table 7 shows the observation to demonstrate the results of water absorption of building blocks.

Tab. 7 - Water absorption of building blocks

Specimen	Dry weight W_1 gm	Weight (after 24 hours immersion into water) W_2 gm	Water absorption (%) = $(W_2 - W_1)/ W_1 \times 100$
B-0	2390	2630	11.0
B-10	2450	2690	9.90
B-20	2515	2700	10.50
B-30	2580	2795	8.60
B-40	2600	2835	9.00
B-50	2645	2875	8.80
B-60	2685	2915	8.60
B-70	2700	2915	7.95
B-80	2735	2960	8.20
B-90	2760	2985	8.15

Characterization of Building Blocks

Experimental investigations for compressive strength and water absorption capacity were performed to insure the durability of BFS based building block samples as per IS code specifications. Building blocks found free from defects like bloating, cracks and efflorescence as examined on all types of samples from B0 to B10.

Water absorption is an important parameter to indicate open porosity. To ensure external weather resistance, the lower percentage of water absorption is always better. As per IS 12894-2002 [17], the average water absorption not more than 20 percent demonstrates a good quality of building block. (Figure 3) shows water absorption for BFS based building blocks. Maximum percentage of water absorption was found 11.0% proven the requirements as per IS code recommendations.

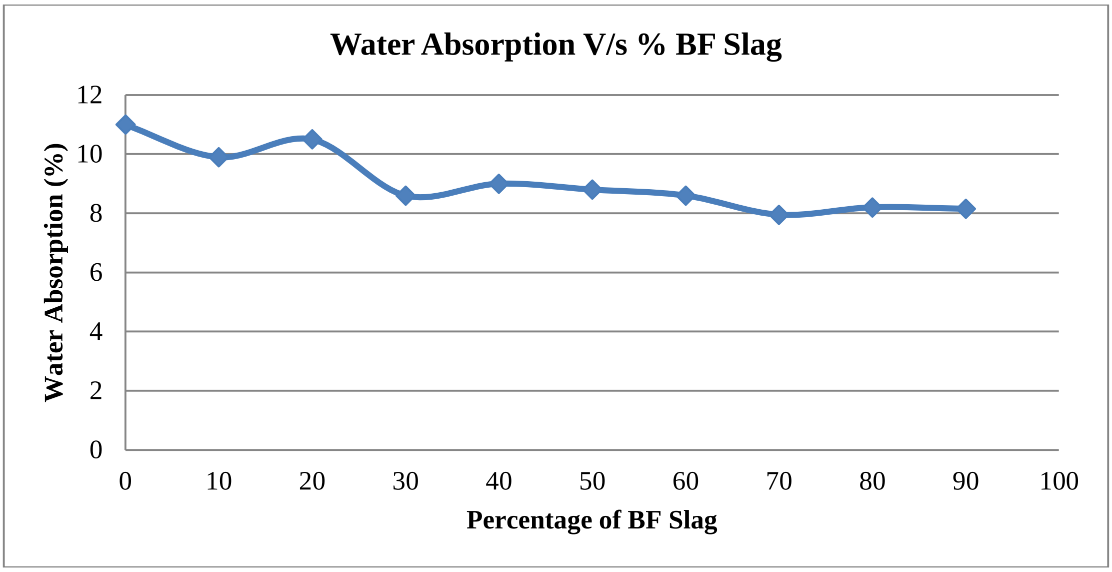

Fig.3 -Water absorption of BFS based building blocks

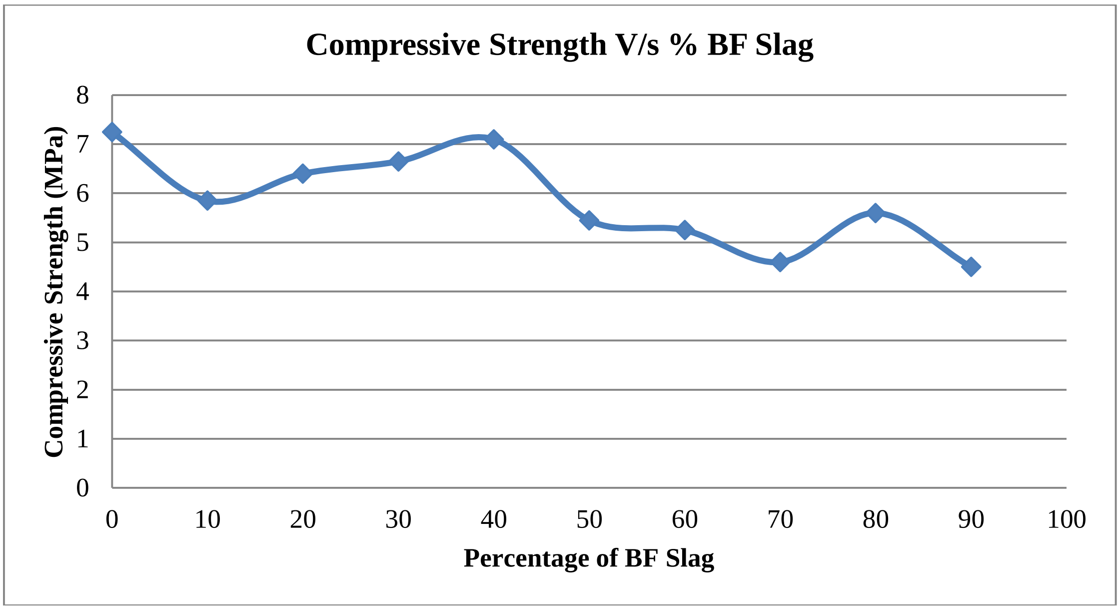

Fig.4- Compressive strength of BFS based building blocks

Compressive strength is the most critical index of building blocks and is shown in (Figure 4). Figure shows, as the percentage of BFS increase from 10% to 40%, compressive strength also increases. Replacements of BFS by more than 50% by volume exhibits decrement in the value of compressive strength. As per IS 1905-1987 [18], minimum compressive strength required by the building block after 28 days curing should not be less than 0.7 MPa for 1:8 mortar mix. Minimum compressive strength achieved by BFS based building blocks was found 4.50 MPa shows good quality requirements.

STATISTICAL MODELING

Development of regression model

A generalized correlation was developed considering experimental data carried out during research work in terms of water absorption, density and compressive strength. This developed correlation was as follows:

$$ACS = -0.03682(A) -0.02171(B) +0.004579(C)$$

Where,
ACS= Average Compressive Strength in MPa, (Dependent variable)
A= Slag (%),
B= Water Absorption (%) and
C= Density of building blocks in (kN/m^3).

Correlation was developed considering 10 observations. The details of selected experimental data to develop correlation are showed in Table 8.

Tab. 8 - Details of selected experimental data to develop correlation

S.No.	Slag (%)	Water Absorption (%)	Density (Kg/m3)	ACS (MPa)
1	0	11	1552	7.25
2	10	9.9	1590	5.85
3	20	10.5	1634	6.4
4	30	8.6	1675	6.65
5	40	9	1690	7.1
6	50	8.8	1715	5.45
7	60	8.6	1745	5.25
8	70	7.95	1754	4.9
9	80	8.2	1775	5.6
10	90	8.15	1795	4.5

The actual and predicted productivity has been carried out for developed regression model and their accuracy was determined through formulations as listed below. Equation (1) shows the formula for Mean Absolute Percentage Error (MAPE) whereas Average Accuracy Percentage (AA%) is presented as Equation (2) [20-21].

Accuracy of developed regression model

$$MAPE= (\Sigma |A-P|/A*100)/n \quad (1)$$

$$AA\% =100 - MAPE \quad (2)$$

The Coefficient of Determination (R^2)

Tab. 9 - Statistical measures results

Measures	(R^2)	MAPE%	AA%	Observations
Results	0.992	7.70	92.30	10

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Results enlisted in Table 9 show that the model is the best fitted on the basis of coefficient of correlation and regression. It is observed that the value of R2, MAPE and AA% by MLR model demonstrates good agreement with the actual measurements.

CONCLUSIONS

The present study indicates feasibility of recycling BFS in the form of fine aggregate to create building blocks using it as a partial to full replacement. Based on the experimental results, following conclusions have been drawn:

- The physical properties of crushed BFS found permissible as desired by the naturally occurring fine aggregates and hence it may be a better alternative.
- To achieve higher weather resistance condition, maximum amount of BFS required to be replaced is 40% by volume. Beyond this limit BFS may replace fully with naturally occurring fine aggregates which may proof resistivity against moderate weather condition.
- Water absorption for BFS based building blocks found adequate to ensure durability and denser nature as required by the conventional bricks.
- Conventional bricks have to undergo kiln process and as result due to burning of fossil fuel in huge, environmental pollution take place. On the other hand, BFS based building blocks are free from kiln process and hence these blocks are pollution free and fuel saving as well.
- Reuse of wastes leads to reduce the scarcity in naturally occurring materials like sand, grit and clay.
- Raw material is derived from waste which may proof financial potential, therefore using BFS based building block overall cost of construction can be minimize.
- The use of environmental friendly walling materials made from industrial waste is still very limited, therefore it may provide a good scope of further research in context to reuse and recycle the wastes for producing cost effective and eco-friendly building materials.
- Awareness can be made to the society for reuse and recycle of waste and also to promote eco- friendly low cost building materials which have inferior acceptance till now.
- Ecological problem related to direct landfilling and incineration of wastes may lessen.

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