Experimental study on fired clay brick production using waste foundry sand and fly ash

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Abstract - *Fired clay bricks are one of the oldest and major walling materials used in India. India is the second largest producer of bricks in the world after China, with about 240 - 260 billion bricks produced annually. Our country is now rapidly urbanizing is expected to have an annual growth rate of about 6.2% in the construction industry. So, there will be higher demands for infrastructure, thus leading to a higher demand for primary building materials like clay bricks. But one of the major disadvantages of clay bricks is the use of large amount of agricultural clay in the manufacturing it, which is a great challenge for farmers. Depletion of this fertile top soil leads to land degradation. So, the main aim of this study is to develop & evaluate the behaviour of fired clay bricks incorporating industrial waste materials such as waste foundry sand & fly ash, thus reducing soil usage. In this work, 10% to 50% by weight replacement of clay in traditional clay bricks to industrial wastes is investigated. Based on the test results, bricks with 30% addition of foundry sand and 10% fly ash are effective and has high strength. Compressive strength of unreinforced masonry of such bricks were also studied by casting prism and wall panels as per IS 1905-1987 and BS EN 1052-1: 1999.*

***Key Words*: Fired clay bricks, waste foundry sand, Fly ash, masonry prism, wall panels, compressive strength, sustainability**

1.INTRODUCTION

India's economy, which is currently the fifth largest in the world, is anticipated to overtake the top three in the next ten to fifteen years. Further due to increase in population growth, we have seen tremendous urban progress. The overall urban population had increased from 217.17 million in 1991 to about 377.1 million in 2011 & the number of cities & towns had increased from 3,768 to 7,951. It is estimated that by 2030, more than 400 million people will be living in cities in India [1]. These will result in major demand for infrastructure and housing, which will in turn increase the demand for construction materials. Also, the government has launched programs such as 'Smart India Mission,' which aims to develop 100 existing cities to smart cities, which has again boosted the construction demands. But this has major disadvantages like consumption of natural resources for material production, such as quarrying raw materials for cement, agricultural clay for brick production etc.

This serious problem of natural resource depletion can be overcome by recycling industrial wastes in the production of construction materials. So, this study focusses on utilization of industrial waste materials such as waste foundry sand (WFS) from metal casting industry and fly ash (FA) from thermal powerplant in sustainable brick production. Various studies have been conducted on the incorporation of industrial wastes in brick production. Safeer Abbas et al. (2017) [2] reported findings of bricks manufactured using FA and conventional earthen materials, concluding that about 5% of FA added bricks can be used as severe weather resistant brick. Whereas, bricks with 20% FA addition can be used as moderate weather resistant bricks and about 10% FA can be utilized effectively. Nabil Hossiney et al. (2018) [3] studied on the utilization of WFS in clay bricks by mixes 0%, 30%, 40% & 50% WFS. Found a minimum compression resistance of 3.3 MPa and maximum water absorption of 21.6% for 50% WFS incorporated bricks. Also, concluded insignificant difference in apparent porosity, and specific gravity compared to commercial bricks.

In this work, the combination of industrial wastes (WFS and FA) on the properties of fired clay brick was studied. 5 mixes were selected with WFS varying from 0 to 40% by weight of clay, while keeping a constant proportion of 10% FA. An optimization study was then conducted by various tests as per IS 1077: 1992[4] to select the best brick specimen. The compressive strength of unreinforced masonry of such bricks were also studied by casting prism and wall panels as per IS 1905-1987[5] and BS EN 1052-1: 1999[6].

2. Experiment and methods

2.1 Materials used

The materials used for the study includes Waste Foundry sand (WFS), Clay and Fly ash (FA).

2.1.1 Foundry Sand

Waste foundry sand (WFS) is a discarded material produced from ferrous (iron & steel) & non-ferrous (copper, aluminium & brass) metal casting industries, which is used to create moulds & cores. About 95% of the WFS is generated by suppliers of automotive industry & it's parts. The waste foundry sand was accumulated from the metal casting unit of Autokast Ltd, Kerala. Obtained foundry sand was tested for specific gravity using pycnometer and fineness modulus by sieve analysis. Specific gravity was found to be 2.28 and fineness modulus 1.9.

2.1.2 Clay

Clay is the most integral material in brick making and was sourced from local brick kiln nearby. Clay when wet with water possess a high degree of tenacity and plasticity. It can be moulded into different shapes, then dried and burned to produce various products such as tiles, terracotta, bricks etc. The particle size distribution, plastic properties of clay mixture were found out along with specific gravity. The specific gravity of clay was found to be 2.31. Liquid limit (LL) and plastic limit (PL) values obtained were 45 and 29.54 respectively.

Plasticity index = LL – PL
= 45 – 29.54
= 15.46

The plasticity index obtained was within the limit (15-25) as per IS 2117: 1991[7].

Fig -1: Fly Ash

Fig -2: Waste foundry sand

2.1.3 Fly Ash

Fly ash (FA) or pulverized fuel ash or coal ash is a fine waste material from thermal power plants obtained after coal combustion. FA was sourced from Nouka FTC Logistics, Ernakulam. The specific gravity of fly ash was tested using Le Chatlier's apparatus and was found to be 2.0.

Table -1: Chemical composition of raw materials.

Element	Composition (% by weight)		
	Clay	WFS	FA
SiO_2	61.42	81.02	55.12
Al_2O_3	15.59	5.73	23.41
Fe_2O_3	14.8	5.48	6.05
CaO	0.24	1.12	3.60
MgO	0.31	1.34	0.44
TiO_2	0.23	-	-
Na_2O	-	0.12	1.08

2.2 Manufacturing of Brick

Brick manufacturing was done in a local brick kiln. Raw materials were mixed manually in different proportions using hand. 5 mix proportions were selected as in "table2" i.e., 0%, 10%, 20%, 30% and 40%WFS incorporation by weight, while keeping 10% FA constant [2] and water addition of about 10 to 14% to get a homogenous mix.

Table -2: Trial-Mix Proportioning

Sl No	Clay (Kg)	WFS (%)	WFS (Kg)	FA	Designation
1	94.5	0	0	10%(10.5kg)	F0
2	84	10	10.5	10%(10.5kg)	F10
3	73.5	20	21	10%(10.5kg)	F20
4	63	30	31.5	10%(10.5kg)	F30
5	52.5	40	42	10%(10.5kg)	F40

A total of 150 bricks were produced for different brick compositions by machine moulding technique. The brick dimensions adopted were 230 x 110 x 75 mm. The moulded bricks were kept for drying for a period of 15 days. The bricks were then transported and manually loaded in kiln chambers. Bricks are burned for a period of 24 hours under a firing temperature of about 1100°Cand kept for cooling for a period of 2-3 days.

Fig -3: Bricks kept for drying

Fig -4: Finished bricks

2.3 Testing of bricks

The finished bricks were tested for various mechanical and durability properties as specified by IS 1077: 1992 and IS 3495 part 1-4 [8].

2.3.1 Compressive Strength

The bricks were tested for compressive strength in accordance with IS 3495-1. The bricks, after immersing in water for 24 hours were then filled with mortar (1:3) on the testing surface and were kept under damp jute bag for 24 hrs. later immersed in water for 3 days before testing. The dried specimens were then placed in the compression testing machine of capacity 2000 KN between two 3mm thick 3 ply plywood sheets. Results are tabulated in table 3.

2.3.2 Water Absorption

Conducted as per IS 3495-2 to identify the amount of water absorbed by the brick specimen after it has been immersed in water for 24 hrs. It was found that all the bricks were having water absorption value within the limit (20%) as per IS 1077: 1992. Results are tabulated in table 4. An average of 5 bricks were tested for each mix.

2.3.3 Efflorescence

Determined as per IS 3495-3, efflorescence is the deposit of water-soluble salts formed on the surface of bricks. In this test, the bricks are kept upright in a flat dish with water filled to a height of 25mm. Water is filled twice and allowed to evaporate and then inspected for salt deposits. Slight efflorescence i.e., <10% of the exposed area with salt deposition was observed in F30 and F40 specimens while efflorescence was nil in others.

2.3.4 Hardness

The bricks were scratched with a nail and is observed for any impressions. No impressions were observed on F20 and F30 bricks, while others had impression.

Table -3: Compressive strength of bricks

Mix	Compressive Strength(N/mm^2)
F0	10.79
F10	7.42
F20	8.53
F30	9.63
F40	8.61

Table -4: Water absorption of bricks

Mix	Initial Wt. (Kg)	Wt. after 24 hr water immersion (Kg)	Water absorption (%)
F0	2.726	3.271	19.9
F10	2.708	3.226	19.12
F20	2.795	3.324	18.92
F30	2.961	3.502	18.27
F40	3.019	3.578	18.51

2.3.5 Bulk density

The bulk density of the bricks was also found out “table 5” as per ASTM C20 [9]. It is the ratio of dry weight of the brick to its volume.

Table -5: Bulk density of bricks

Mix	Bulk density (g/cm^3)
F0	1.771
F10	1.746
F20	1.734
F30	1.766
F40	1.703

2.3.6 Soundness

In this test, two bricks are struck one another. Bricks are considered to be sound if they make a clear metallic ringing sound without breaking. All the brick specimens passed the soundness test.

From the results obtained from the above tests conducted, WFS and FA incorporated bricks can be classified as class II bricks as per IS 1077: 1992. They can be used in permanent building structures with a coat of plaster. Also, can be used for single-storied load-bearing structures. Among the different mix proportions considered, F30 specimen with FA 10% and WFS 30% by weight can be adopted as the best specimen with least water absorption value of 18.27% and compressive strength of 9.63 N/mm^2.

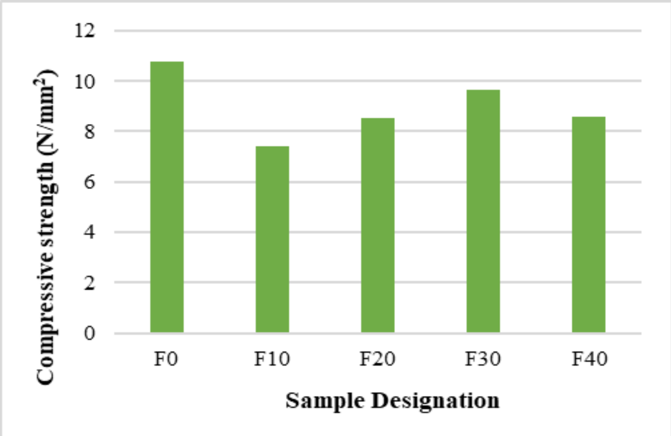

Chart -1: Compressive strength of bricks

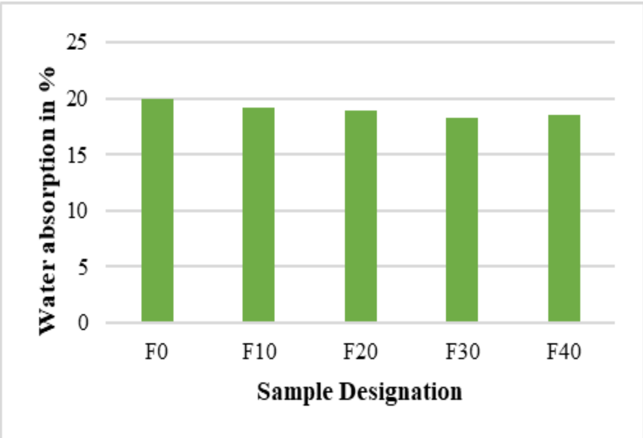

Chart -2: Water absorption of bricks

2.3 Masonry Specimens

To understand the masonry behavior of the optimized brick specimen, masonry prisms are prepared and tested for compressive strength as per IS 1905-1987 [5] and wall panels as per BS EN 1052-1: 1999 [6]. The compressive strength values of masonry assemblages are required for designing as well as repair of masonry structures [10].

As per appendix B of IS 1905-1987, the assembled masonry specimen should at least be 40cm high and should have a height to thickness (h/t) ratio of at least two but not more than five. So, as per the dimensions of the brick and code provision, 3 specimens of average dimensions 230 x 230 x 495mm "Fig.5" and average h/t ratio 2.15 were prepared and tested for compressive strength after 28 days curing. In this study, the prisms were casted with 10mm thick cement mortar of mix proportion 1: 6, which was selected as per the provisions of IS 2250: 1981 [11].

Fig -5: Masonry prisms

2.4.1 Test procedure

The prisms were tested after 28 days curing by placing between plywood sheets of 4mm thickness in universal testing machine (UTM) of 1000 kN capacity. Compressive strength values obtained by the test is multiplied by a correction factor specified in table 12 of IS 1905-1987 to get the actual compressive strength values.

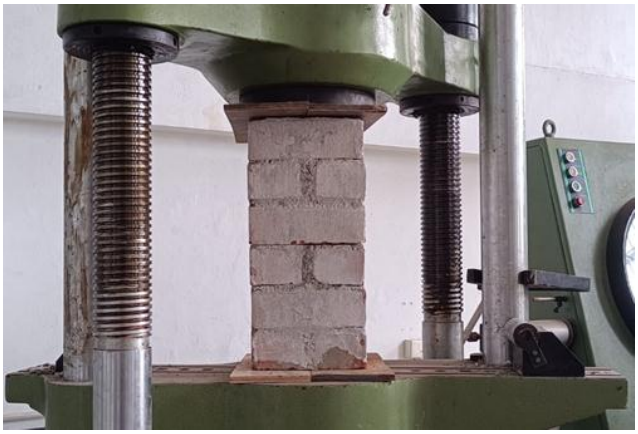

Fig -6: Testing of masonry prism

Masonry wall panels were also constructed and the compressive strength studied with average dimension 850 x 230 x 345mm and 10mm thickness mortar joints. The specimens were tested in UTM after curing for 28 days as specified in BS EN 1052-1: 1999 [6]. To transfer the compressive load from the machine as uniformly distributed load an I section beam was placed on top.

The dimensions of the panels are selected such that it falls within the criteria laid down in table 3 of BS EN 1052-1: 1999.

The compressive strength of the masonry is calculated by the relation:

$$fi = \frac{Fimax}{Ai} \quad \text{N/mm}^2 \qquad \text{... (1)}$$

Where, fi is the compressive strength of the individual masonry specimen.

$F_{i\,max}$ is the maximum load reached and A_i is the loaded cross-section of the specimen.

Fig -7: Testing setup of wall panels

3. RESULTS AND DISCUSSION

3.1 Compressive strength of masonry prism

The obtained values of compressive strength of prisms were multiplied with a correction factor of 0.749 obtained from table 12 of IS 1905-187 to obtain the normalized compressive strength (f'm) of the masonry. The average value of compressive strength obtained was 2.356 MPa, "table 6", which was compared with the results of other researchers according to the mortar selected and the strength of brick units [13][14].

Basic compressive stresses of the masonry were also found out and was compared with the values specified in IS 1905-1987 for the type of mortar and compressive strength of brick units. Average value of basic compressive stress obtained as per prism test was 0.589Mpa and as per table 8 of IS 1905-1987 [10] was 0.77 MPa for bricks of compressive strength 9.63Mpa and 1:6 mortar proportion.

Table -6: Compressive strength of prism

Sl No.	Compressive strength (MPa)	Compressive strength (MPa) after applying correction factor: 0.749	Average Value (MPa)
1	3.04	2.276	2.356
2	3.175	2.378	
3	3.08	2.307	

3.2 Compressive strength of wall panels

The compressive strength of wall panels was found out as per the procedure laid down in BS EN 1052-1: 1999 and was compared with the compressive strength values specified in table 2 of BS 5628-1:1992 [12] for specific mortar proportions and compressive strength of brick unit. Results are tabulated in table 7.

Table -7: Compressive strength of wall panels

Sl No.	Compressive strength (MPa)	Average Value (MPa)
1	2.035	2.01
2	2.007	
3	1.988	

Average value of compressive strength obtained by experimental testing is 2.01N/mm², which was lower than value provided in table 2 of BS 5628-1:1992. As per table 2 the characteristic compressive strength of masonry with mortar type iv (1:6) and brick unit of compressive strength 9.63Mpa was 3.4 N/mm².

3.3 Mode of failure

It was observed that vertical splitting cracks were predominant in the failure of masonry prism specimens. Vertical cracks originated mainly at middle of the specimen on all sides, which is mainly due to outward bursting force arising, as reported by several researchers [13].

Vertical cracks propagated through the bricks and mortar, while horizontal cracks through the mortar bed joint were very few or nil, indicating good bond strength. While in case of wall panels along with vertical splitting crack, inclined cracks were also predominant. Inclined cracks mainly originated near the supports.

Fig -8: Failure of wall panels

Fig -9: Failure of masonry prisms

4. CONCLUSIONS

In this study, experimental investigations were done to understand the effectiveness of using waste foundry sand and fly ash by replacing certain amount of clay in fired clay brick production. It was possible to produce WFS and FA incorporated bricks by local condition and with minimum processes without any effect on the physical appearance. Among the 5 mixes selected, it was found that F30 specimen with 30% WFS and 10% FA can be effective with a compressive strength value of 9.63 N/mm2. Reduction in compressive strength and increase in water absorption was found for specimens after F30. F30 bricks can be classified as class II bricks as per IS 1077: 1992 and can be used for load bearing single-storied structure.

Experimental investigation of compressive strength of masonry specimens using F30 specimens were done and found that the average compressive strength of masonry prism as 2.356N/mm^2. Basic compressive stress obtained is 0.589Mpa, which was lesser compared to value specified by IS 1905-1987 (0.77Mpa). Compressive strength of wall panels was obtained as 2.01Mpa which is less than specified in BS 5628-1:1992 (3.4Mpa). The former value should be considered while designing masonry using these bricks. Much studies should be done in the future in order for the commercial application of proposed bricks.

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