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ORIGINAL CONTRIBUTION

Investigating the Utility of Iron Ore Waste in Preparing Non-fired Bricks

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Abstract Iron ore waste is a major problem for mine owners due to the difficulty involved in its storage, handling and other environmental related issues. An alternative solution to this is utilisation of iron ore waste (IOW) as some value added product in construction industry. An attempt has been made in this paper in examining the possibility of making non-fired bricks from iron ore waste with some additives like cement and fly-ash. Each of the additives were mixed with IOW in different ratios and different sets of bricks were prepared. The prepared IOW bricks were cured for 7, 14, 21 and 28 days and their respective compressive strength and percentage of water absorption were determined. The results show that IOW bricks prepared with 9% and above cement and with 28 days of curing are suitable for brick making and meet the IS specifications. It was also observed that the weight of the prepared bricks with 9% cement with 28 days of curing varies between 2.35 and 2.45 kg whereas the weight of compressed fire clay bricks varies from 2.80 to 2.89 kg. Results also show that the cost of bricks prepared with cement ranging from 9 to 20% is comparable to that of commercially available compressed bricks.

Keywords Iron ore waste · Fly-ash · Additives · Bricks · Compressive strength · Water absorption

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Introduction

Mining is the backbone of any country's economy. Iron ore mining plays a significant role in production of steel and other metals, but at the same time generates massive waste/tailing which pollutes the environment and brings other issues related to its storage and handling. Hence, there is a need to develop a comprehensive plan for utilisation, storage of iron ore waste/tailings from the point of view of saving resources and sustainable development. Iron ore wastes are the ones from which iron ore has been extracted profitably. Iron ore waste has low percentage of Fe_2O_3, hence it is discarded. Iron ore waste is dumped at relevant place as per the approved mining plan. It occupies large area within the lease boundary, degrades surrounding land and also deteriorates the environment.

In general, any building material is directly or indirectly prepared from the Earth's crust. The basic composition of building materials is nearly same as the composition of Earth (i.e. Silica, Aluminum oxide, Iron etc.). In the recent years, there has been a significant demand for building materials in India as well as all over the world. Therefore, it is imperative to use mining and mineral wastes in the production of bricks, paving blocks and other value added products which are used in the construction industry [1, 2]. Since the need for building materials is growing at an alarming rate, therefore in order to meet the demand for new buildings, new ways and techniques must be evolved for brick making. Manufacturing of building materials like brick, cement, steel, aggregates, etc. which are consumed in bulk quantities, puts great pressure on natural resources (raw materials) and are highly energy demanding. Therefore, the use of alternative material for brick manufacturing should be encouraged. Hence, there is a scope for utilizing mine wastes for the manufacturing of building material and other products. Mine wastes and tailing can be converted into bricks/paving blocks, which can meet the demand of brick in metropolitan cities for the next 30 years or even more. Similarly, utilizing the iron-ore waste/tailings can fulfill the requirements of bricks for Karnataka state for many decades [1]. Thus, there is great potential for utilizing mine wastes to manufacture building materials and products.

The crux of this investigation is the possibility of making bricks by mixing iron ore waste with other additives like cement and fly ash. In this investigation, the iron ore waste percentage (by mass) was varied from 65 to 90, whereas that of cement was varied from 5 to 30. The cement percentage was restricted to a maximum of 30%, based on the study carried out by various other investigators [3–5]. Similarly, the fly ash percentage by mass was varied from 5 to 30. The testing and evaluation of bricks prepared has been done based on parameters such as compressive strength and water absorption [6, 7].

Study Area

The investigation was carried out in a mine located in Bellary district, Karnataka, which is a large mine with two leases each with an area of 1863 Ha and 143 Ha. One of the lease has 3 iron ore, 36 manganese and 2 with both iron and manganese ore pits, whereas the other lease has 8 manganese ore pits. Overall both the mining leases (ML) have 53 mining pits (41 in 1st mining lease, 8 in 2nd mining lease and 4 common pits to both the leases with both iron and manganese ore) and 110 waste dumps (83 in 1st mining lease and 27 in 2nd mining lease).

Collection of Sample

Iron ore waste samples (silt) were collected from the bottom of the dumps and close to the check dams (as there was water in the check dam), earthen dam and settling tank as per the advice from the concerned mining firm. A total of nine iron ore waste samples were collected from nine different locations in consultation with the mine management. However, samples collected from only six locations were considered for this study based on the chemical composition, especially the Fe_2O_3. Three samples where in Fe_2O_3 was more than 30%, was not considered as waste as they could be upgraded to iron ore in near future. The snap shot of google map showing various sample locations through GPS is shown in Fig. 1. While collecting the sample the top layer of settled silt material was discarded to avoid the unwanted material deposited and the iron ore waste from 3 to 5 cm depth was taken for investigation. Fly ash for the present investigation was collected from a nearby thermal power plant (Udupi Power Corporation Ltd.) which was around 10 km from the institute.

Fig. 1 Snap shot of google map showing various sample locations through GPS

Material Properties

The various analysis which were carried out on the materials were:

Iron ore waste: Sieve analysis, Atterbergs limit, Chemical composition and specific gravity.
Cement: Chemical composition and specific gravity.
Fly-ash: Chemical composition and specific gravity.

Sieve analysis was carried out in the Mineral Processing Laboratory of the Department of Mining Engineering. It gives an idea about the size distribution of particles in a given sample. The methodology of sieve analysis was as per IS 2720 (Part IV):1985 [8].

Similarly, liquid limit, plastic limit, plasticity index and shrinkage limit tests were carried out in the Geo-technical Laboratory and Soil Laboratory of the Department of Civil Engineering. These parameters were tested and analysed according to IS: 2720 (Part V):1985 [9]. Since iron ore waste (IOW) sample has less liquid and plastic limit properties and also due to lack of plasticity, the iron ore waste could not be directly used for brick making. However, the IOW sample, when mixed with additives like cement and fly ash, provided plasticity to the material.

Specific gravity test for cement, iron ore waste and fly-ash was carried out by using Pycnometer in the Soil Laboratory of the Department of Civil Engineering. The specific gravity of all materials was analysed according to IS-2720 (Part III/Sect.2):1980 [10].

The chemical composition of iron ore waste (IOW), fly ash and cement was carried out in the Chemical Engineering Department of NITK Surathkal, by sending representative sample obtained through Conning and

Quartering in the Mineral Processing Laboratory of Department of Mining Engineering.

Preparation of Iron Ore Waste Bricks

As the collected iron ore waste (IOW) sample was in the form of powder, it did not require further processing like crushing and grinding. Hence, the collected samples were directly suitable for mixing with additives for brick making. For preparing the bricks, iron ore waste was taken as a major aggregate in combination with fly ash and cement. The bricks were prepared with five different combinations of above said aggregates (i.e. cement, fly ash and iron ore waste) by mass percentage as given in Table 1. In a similar fashion, bricks were prepared with IOW percentage of 70, 75, 80, 85 and 90 and these mixtures were named as A1 to E1 for IOW of 70%, A2 to D2 for IOW of 75%, A3 to C3 for IOW of 80%, A4 to B4 for IOW 85% and A5 for IOW of 90% (Table 2).

Bricks were prepared using 30 cast iron metallic moulds which were specifically fabricated for this purpose. During brick making, oil was applied to the inner part of the mould and the prepared mixture was poured slowly into it so that it spreads evenly inside the mould. After filling the mould with mixture, load of 20 MPa was applied (based on the earlier studies carried out by various investigators [11, 12]) to each brick for proper compaction of bricks (Fig. 2). The size of bricks prepared was 190 mm × 90 mm × 90 mm [13].

The bricks were prepared with different ratio of cement (C), fly ash (FA) and iron ore waste (IOW) which are designated as A, B, C, D, E and F as given in Table 1. The prepared bricks were kept for 24 h in the mould and then removed and kept under sunlight for drying. Proper curing was done by spraying water for 7, 14, 21 and 28 days, as shown in Fig. 3. For each number of curing days, five bricks were tested for its compressive strength and five for its water absorption, as per Bureau of Indian Standards [6, 7].

Table 1 Composition for different types of mixes with IOW 65% [5]

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron ore waste (IOW)
A	30	05	65
B	25	10	65
C	20	15	65
D	15	20	65
E	10	25	65
F	05	30	65

In the process of brick making, it was observed that bricks which were prepared with 5% cement, were not stable and many of them deformed once removed from the mould (Fig. 4). However an attempt was made to prepare and test the bricks of this mix ratio too for the purpose of comparison of results.

Assessment of Quality of Bricks

The quality of bricks was assessed as per BIS Standards which is based on compressive strength [6] and water absorption of the bricks [7]. The compressive strength should always be more than 3.5 MPa and the water absorption of a good brick should be less than 20% after 24 h of immersion in water [14–16].

Compressive Strength

The bricks were tested for its compressive strength using universal compression testing machine as shown in Fig. 5. The axial load was applied at a uniform rate of 14 N/mm^2 per minute as per IS standard IS 3495 (Part 1):1992, till the failure of the brick and maximum load at failure was recorded. This procedure for testing of compressive strength was followed for of all sets of prepared bricks. The average compressive strength of each type of brick was computed and is given in Table 2.

Water Absorption

To determine the water absorption capacity of different bricks, initially the weight of the dry bricks (dry weight) was taken. The bricks were then immersed in a container which is filled with water of known quantity for 24 h at room temperature (Fig. 6). Necessary steps were taken to avoid unnecessary evaporation of water by closing the container with a lid. After 24 h, the bricks were taken out of the container and excess water on the surface was cleaned using tissue paper. The final weight of the brick was taken to calculate the percentage of water absorption. This process was carried out for all the combination of mixtures, the average values of water absorption which is given in Table 2.

Results and Discussion

Sieve Analysis

The results of sieve analysis for iron ore waste (IOW) is given in Table 3. The cumulative percentage retained versus sieve size is shown in Fig. 7. As it can be seen from Fig. 7, almost 95% of the sample is less than 600 micron size. The remaining

Table 2 Results of compressive strength and water absorption

Mix ratio	No. of curing days									ΔWS
	7	14	21	28	ΔCS	7	14	21	28	
	Avg. compressive strength (MPa)					Avg. water absorption (%)				
	1	2	3	4	**4–1**	5	6	7	8	**5–8**
C:FA:IOW 30:05:65 (Ratio A)	6.86	7.23	8.56	11.69	**4.83**	14.23	8.81	6.76	5.48	**8.75**
25:10:65 (Ratio B)	5.67	6.65	8.10	11.20	**5.53**	13.73	8.74	6.63	5.40	**8.33**
20:15:65 (Ratio C)	4.77	5.45	6.73	10.81	**6.04**	13.41	8.70	6.60	5.31	**8.10**
15:20:65 (Ratio D)	4.39	5.44	6.46	10.55	**6.16**	12.93	8.70	6.57	5.25	**7.68**
10:25:65 (Ratio E)	2.32	3.37	4.14	4.46	**2.14**	12.10	8.55	6.48	5.17	**6.93**
05:30:65 (Ratio F)	0.56	0.61	0.61	0.66	**0.10**	11.40	8.47	6.38	5.48	**5.92**
A–F	**6.30**	**6.62**	**7.95**	**11.03**		**2.83**	**0.34**	**0.38**	**0.00**	**2.83**
30:00:70 (Ratio A1)	7.88	8.77	11.23	11.59	**3.71**	14.30	8.80	6.80	5.43	**8.87**
25:05:70 (Ratio B1)	5.82	7.43	7.62	8.69	**2.87**	13.68	8.73	6.75	5.38	**8.30**
20:10:70 (Ratio C1)	4.59	5.37	6.68	6.94	**2.35**	13.51	8.69	6.74	5.32	**8.19**
15:15:70 (Ratio D1)	3.19	4.39	4.15	4.48	**1.29**	12.89	8.64	6.72	5.27	**7.62**
10:20:70 (Ratio E1)	2.74	2.86	2.99	3.15	**0.41**	12.49	8.55	6.66	5.22	**7.27**
A1–E1	**5.14**	**5.91**	**8.24**	**8.44**		**1.81**	**0.25**	**0.14**	**0.21**	**1.60**
25:00:75 (Ratio A2)	11.63	11.68	11.81	11.95	**0.32**	14.41	8.78	6.83	5.31	**9.10**
20:05:75 (Ratio B2)	8.61	8.78	8.95	9.47	**0.86**	14.36	8.59	6.78	5.38	**8.98**
15:10:75 (Ratio C2)	7.41	8.09	8.16	8.38	**0.97**	14.34	8.76	6.74	5.44	**8.90**
10:15:75 (Ratio D2)	2.67	2.93	3.80	4.45	**1.78**	14.27	8.74	6.67	5.38	**8.89**
A2–D2	**8.96**	**8.75**	**8.01**	**7.50**		**0.14**	**0.04**	**0.16**	**0.13**	**0.01**
20:00:80 (Ratio A3)	4.49	4.77	5.10	5.79	**1.30**	14.34	8.72	6.79	5.38	**8.96**
15:05:80 (Ratio B3)	3.07	4.30	4.52	5.49	**2.42**	14.27	8.65	6.74	5.33	**8.94**
10:10:80 (Ratio C3)	2.51	3.04	3.27	3.65	**1.14**	14.20	8.57	6.70	5.29	**8.91**
A3–C3	**1.98**	**1.73**	**1.83**	**2.14**		**0.14**	**0.15**	**0.09**	**0.09**	**0.05**
15:00:85 (Ratio A4)	2.46	2.50	3.45	5.32	**2.86**	14.30	8.62	6.71	5.30	**9.00**
10:05:85 (Ratio B4)	1.84	2.67	2.73	3.53	**1.69**	14.28	8.56	6.64	5.24	**9.04**

Table 2 continued

Mix ratio	No. of curing days									ΔWS
	7	14	21	28	ΔCS	7	14	21	28	
	Avg. compressive strength (MPa)					Avg. water absorption (%)				
	1	2	3	4	**4–1**	5	6	7	8	**5–8**
A4–B4	**0.62**	**−0.17**	**0.72**	**1.79**	**1.17**	**0.02**	**0.06**	**0.07**	**0.06**	**−0.04**
10:00:90 (Ratio A5)	**1.49**	**1.60**	**1.79**	**2.23**		**14.09**	**8.24**	**6.53**	**5.03**	**9.06**

Values in bold indicate the difference between the highest and lowest value for different cases in a particular column and row

Fig. 2 Application of load for brick compaction

Fig. 3 Curing of bricks

around 5% is also below 75 microns which will not affect the brick making process. Therefore the particle size with 600 micron (collected sample directly used) was used in preparation of bricks in this investigation.

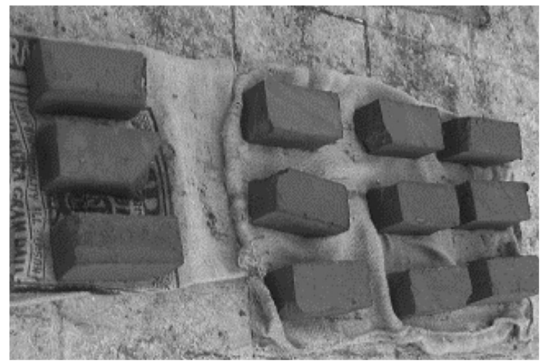

Fig. 4 Deformation in iron ore waste bricks with 5% cement as an aggregate

Fig. 5 Testing of bricks for its compressive strength

Atterberges Limits and Specific Gravity

The percentage of Atterberges limits of iron ore waste are: liquid limit-48 (the liquid limit is defined as the moisture content at which the material passes from the plastic state to liquid state), plastic limit-28 (plastic limit is defined as the moisture content in percent, at which the soil crumbles, when rolled into threads of 3.2 mm in diameter. Plastic limit is the lower limit of the plastic stage of soil), plasticity

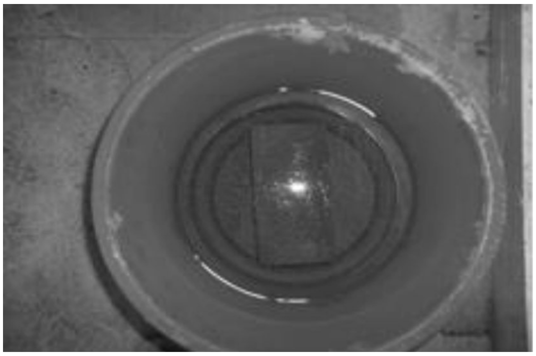

Fig. 6 Water absorption test carried out for prepared bricks

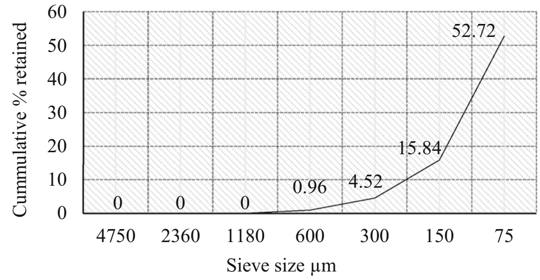

Fig. 7 Results of sieve analysis on IOW samples

index-20 and shrinkage limit-18 (the moisture content in percent at which the volume of the soil mass ceases to change is defined as the shrinkage limit). The specific gravity of cement, iron ore waste and fly ash were measured and they are 3.15, 3.18 and 1.90 respectively.

Chemical Composition

Iron Ore Samples (IOW)

The various constituents (in percentage) in different IOW samples i.e. S1–S9 were studied and are given in Table 4. The main aim was to know SiO_2, Al_2O_3 and Fe_2O_3 percentage which influences better bonding in the product and gives better compressive strength to the bricks. However, the impact of various constituents of IOW on its compressive strength is beyond the scope of this paper and will not be discussed further.

Portland Cement

Ordinary Portland cement of 43 grade, confirming to IS: 8112-1989 [17] was used as binding material for the preparation of bricks. As the cement was finer than the iron ore waste sample, it could be used as a binding material/additive. Fineness or particle size of Portland cement affects the rate of hydration, which is responsible for the strength gain. Table 5 gives the chemical composition of cement.

Fly Ash

Table 6 gives the chemical composition of fly ash, which was collected from thermal power plant (UPCL, Udupi Dist. Karnataka). Fly ash are suspended particles that are toxic in nature and found in the exhaust gases. Fly ash is widely used for commercial purposes by mixing with other cementing materials. The fine fly ash particles (less than 45 μm) displaces water between the cement particles and act as hydration sites for the cement, thereby improving the concrete pore structure and stimulating early strength development.

Water Absorption and Compressive Strength of Bricks

The results of average water absorption and average compressive strength of bricks is given in Table 2. The compressive strength results obtained for different curing periods for bricks prepared with mix ratio of 7% cement (65% IOW, 7% Cement and 28% Fly ash), 8% cement (65% IOW, 8% Cement and 27% Fly ash) and 9% cement (65% IOW, 9% Cement and 26% Fly ash) are given in Table 7. The water absorption results obtained for different

Table 3 Sieve analysis data for iron ore waste sample

Sieve size (μ)	Mass retained (gm)	Mass passed (gm)	% Retained	Cumulative % retained	Cumulative % passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	0.0	500.0	0.00	0.00	100.00
600	4.8	495.2	0.96	0.96	99.04
300	17.8	477.4	3.56	4.52	95.48
150	56.6	420.8	11.32	25.84	84.16
75	184.4	236.4	36.88	52.72	47.28
<75	236.4	0.0	47.28	100.00	0.00

Table 4 Chemical composition of IOW (% by mass)

Sample no.	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
S1	0.03	0.19	22.27	40.70	0.05	4.79	1.20	22.93
S2	0.89	0.10	27.53	33.02	0.08	3.65	0.94	27.24
S3	0.07	0.06	34.00	40.24	0.06	5.54	1.56	15.20
S4	0.06	0.80	21.42	50.80	0.05	6.85	0.55	20.18
S5	0.04	0.36	25.32	50.13	0.03	3.32	0.85	15.38
S6	0.15	0.02	22.98	21.20	0.07	5.40	0.70	58.88
S7	0.12	0.10	30.45	38.80	0.14	6.52	0.65	32.08
S8	0.37	0.30	13.90	29.45	0.05	2.08	0.36	48.10
S9	0.13	0.27	16.40	41.70	0.14	7.11	1.50	29.45

Table 5 Chemical composition of cement (% by mass)

Chemical composition (%)	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	MgO	M_nO_2	C_aO	Z_nO	P_b	C_r
Cement	18.71	10.44	6.47	0.34	0.43	0.00	0.12	51.46	1.05	1.68	0.01

Table 6 Chemical composition of fly ash (% by mass)

Fly ash (%)	Chemical composition (%)									
	SiO_2	Al_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	MnO_2	Fe_2O_3
0.14	34.80	14.10	16.16	2.70	1.30	5.30	0.86	0.50	0.20	24.14

curing periods for bricks prepared with 9% cement, 8% cemsurvey was carried out with regardent and 7% cement are given in Table 8.

Effect of Curing Days on Compressive Strength of Bricks

The variation in compressive strength with respect to number of curing days is shown in Fig. 8 and the change in compressive strength (ΔCS) from 7 to 28 days for different ratios is shown in Fig. 9.

For Ratio A to Ratio F, it is observed that there is an increase in compressive strength with decrease in cement in the mixture from 30 to 15% with number of days of curing (7–28 days). Though there is decrease in the cement percentage from Ratio A to Ratio D, there is an increase in fly ash percentage (5–20%). This increase in ΔCS from Ratio A to Ratio D may be due to increase in percentage of fly ash. Beyond 15% decrease in cement in the mixture, the compressive strength decreases with curing days (7–28 days). This may be due to decrease in cement beyond a critical value of 15% for effective binding of the mixture. Similar behaviour is observed for Ratios A2 to D2 and A3 to C3.

For Ratios A1 to E1, it is observed that there is a gradual decrease in ΔCS with decrease in cement in the mixture from 30 to 10% with number of curing days (7–28 days). This is a normal feature which will be observed with increase in cement percentage. It is important to note that for Ratios A1 to E1, iron ore waste (IOW) is 70%. This type of behaviour is also observed for Ratios A4 to B4.

Effect of Curing Days on Water Absorption of Bricks

The water absorption of the bricks will influence the durability and strength of the bricks. The effect of curing days on “change in water absorption ΔWA” of bricks for Ratio A to Ratio F is shown in Fig. 10. Similar trend was observed for other ratios mentioned in Table 2.

There is significant decrease in average water absorption with number of curing days/compressive strength. In general, the increase in average water absorption (ΔWA) is from 6 to 9% with curing period of 7 days compared to that of 28 days (Fig. 10). This may be due to presence of more voids with lesser number of curing days and therefore more water absorption. It is also observed that ΔWA values gradually decrease with increase in cement content of the bricks under different curing conditions.

The water absorption of the bricks versus number of curing days is shown in Fig. 11 with 65% of iron ore waste as constant, cement ratio is varied from 30% to 5% and fly-ash ratio is varied 05% to 30% in 5% interval. It also

Table 7 Compressive strength of bricks with cement content of 7, 8 and 9%

Cement (C):Fly ash (FA):Iron ore waste (IOW)												
Proportion of material	Compressive strength (MPa)											
	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample												
S1	0.59	0.64	0.62	0.71	0.68	0.70	0.71	0.74	0.82	1.20	1.90	3.60
S2	0.61	0.62	0.69	0.76	0.66	0.73	0.76	0.77	0.85	1.00	2.20	3.55
S3	0.57	0.65	0.67	0.74	0.70	0.69	0.75	0.79	0.83	0.98	2.35	3.45
S4	0.62	0.60	0.71	0.77	0.69	0.75	0.73	0.75	0.79	1.25	2.40	3.52
S5	0.60	0.63	0.70	0.70	0.71	0.70	0.77	0.74	0.80	1.10	2.25	3.58
Average compressive strength (MPa)	0.60	0.63	0.68	0.74	0.69	0.71	0.74	0.76	0.818	1.11	2.22	3.54

Table 8 Water absorption percentage of bricks with cement content of 7, 8 and 9%

Cement (C):Fly ash (FA):Iron ore waste (IOW)												
Proportion of material	Water absorption (%)											
	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample												
S1	11.50	8.52	7.50	6.40	11.60	8.67	7.58	6.75	11.70	8.96	7.65	6.18
S2	11.52	8.45	7.45	6.45	11.62	8.70	7.55	6.80	11.78	9.00	7.69	6.15
S3	11.54	8.49	7.55	6.39	11.59	8.69	7.60	6.79	11.75	8.90	7.70	6.22
S4	11.57	8.42	7.52	6.52	11.64	8.65	7.62	6.77	11.69	8.97	7.77	6.19
S5	11.59	8.48	7.55	6.50	11.65	8.72	7.59	6.82	11.67	9.02	7.72	6.20
Average water absorption (%)	11.53	8.47	7.51	6.44	11.61	8.68	7.59	6.78	11.73	8.96	7.70	6.19

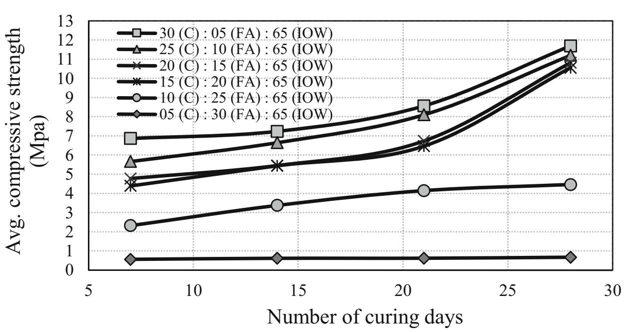

Fig. 8 Compressive strength versus number of cuing days

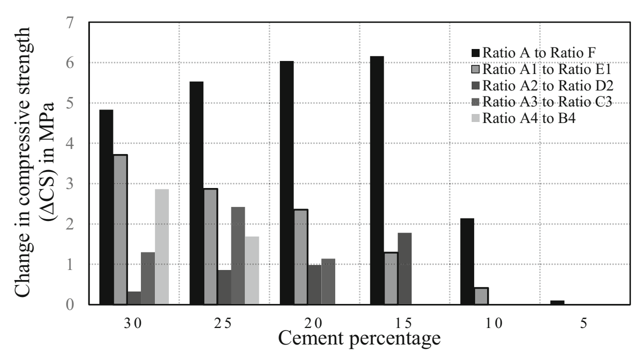

Fig. 9 Change in compressive strength (ΔCS) from 7 to 28 days of curing w.r.t. cement percentage

indicates the variation in percentage of water absorption with respect to number of curing days.

The experimental results shows that the compressive strength of bricks reduces with respect to reduction in percentage of cement in mixture. However, with increase in curing period the minimum strength of bricks could be gained. But in all the cases the water absorption is within the permissible limit for all the mix ratios i.e. less than 20% as per Bureau of Indian Standards (BIS).

Effect of Increase of Cement on Compressive Strength of Bricks

The effect of increase in cement on compressive strength of bricks can be interpreted from Table 2. It is observed that with increase in cement in the mixtures (Ratio F to Ratio A), there is an increase in the average compressive strength with different curing days. A comparision of Ratio F with

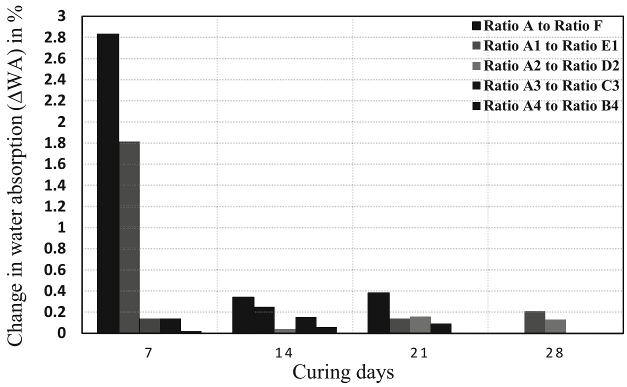

Fig. 10 Impact of curing days on water absorption (ΔWA)

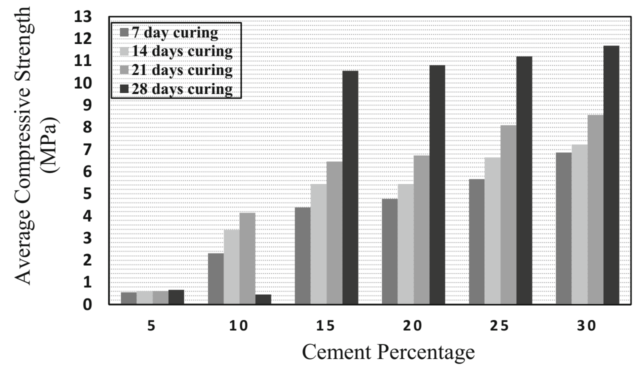

Fig. 12 Impact of cement percentage on average compressive strength for 65% IOW

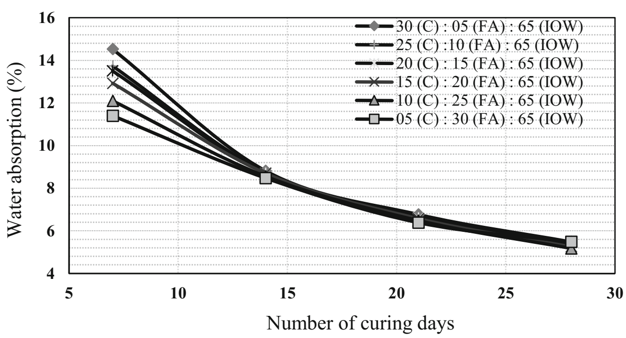

Fig. 11 Variation in % of water absorption with cuing days for 65% IOW

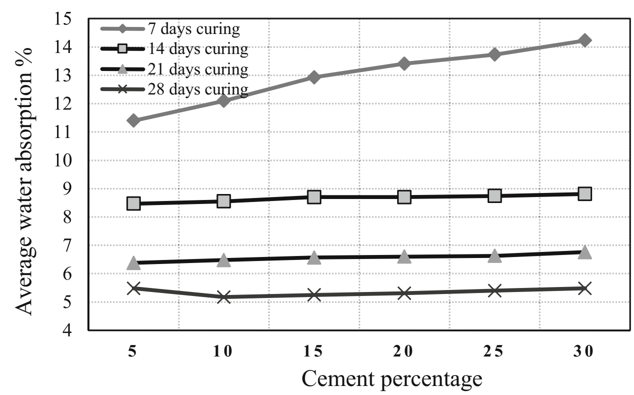

Fig. 13 Average water absorption % versus cement percentage

5% cement with Ratio A with 30% cement indicates an increase in compressive strength of the order of 6.30, 6.62, 7.95 and 11.03 MPa for curing days of 7, 14, 21 and 28 days respectively. Similarly, a comparision of Ratio E1 with 10% cement with Ratio A1 with 30% cement indicates an increase in compressive strength of the order of 5.14, 5.91, 8.24 and 8.44 MPa for curing days of 7, 14, 21 and 28 days respectively which is shown in Fig. 12. Similar increase in compressive strength is also observed for Ratio E1 to Ratio A1.

Even for Ratios A2 to D2 and Ratios A3 to C3, there is a significant increase in compressive strength with increase in cement in the mixture. However, for Ratio A2 to D2, there is decrease in the value of “increase in compressive strength (ΔCS)” with number of curing days. This may be due to higher percentage of IOW in the mixture (75% from Ratio A2–D2 and 80% from Ratio A3–C3) compared to that of 65% (Ratio A–Ratio F) and 70% (Ratio A1 to E1). If IOW percentage is more, in that case a gradual decrease in ΔCS value may be due to particle size of Portland cement, which affects the ratio of hydration, which is responsible for the strength gain.

Effect of Increase of Cement on Water Absorption of Bricks

Increase in cement affects the rate of hydration and hence quantity of water absorption is likely to increase. This phenomenon enhances the strength of the bricks. From Table 2, for Ratio A to Ratio F it is observed that, with increase in percentage of cement in the bricks, the water absorption of bricks as well as its compressive strength increases (Fig. 13). Similar trend was observed for all the ratios i.e. Ratio A1 to E1, Ratio A2 to Ratio D2, Ratio A3 to Ratio C3 and Ratio A4 to B4. Further, the change in water absorption percentage from 7 to 28 days of curing (ΔWA) is also found to reduce with reduction of cement percentage in the bricks.

From Table 8, it was also observed that bricks prepared with cement content of 7, 8 and 9% will satisfy the percentage of water absorption limit as per BIS Standards (<20% when immersed in water for 24 h) for all the days of curing period.

Results of Compressive Strength of Bricks with Less than 10% Cement

The results of compressive strength of bricks with less than 10% cement are given in Table 7. It is seen that bricks with cement content of 9% meets the desired BIS standards of compressive strength at 28 days of curing period. Bricks were also prepared with 65% IOW, 8% cement and 27% fly ash. With 8% cement content, the bricks prepared were with broken edges and their compressive strength was very low and not meeting the BIS standards. Similar results were obtained with 7% cement too. This may be due to lower binding property of the mixture because of lesser cement percentage. Since with 7% cement content, the bricks prepared were not stable and were with broken edges, it was decided not to make any attempt in preparing bricks containing 6% cement.

IOW Brick Vis-à-Vis Burnt Clay Brick-Cost

Cost of Burnt Clay Bricks

A survey was carried out with regard to cost of ordinary burnt clay bricks used for temporary construction as well as cost of compressed burnt clay bricks in different parts of Karnataka. The results of the survey indicated that, the cost of an ordinary burnt clay brick varies from ₹ 5 to ₹ 8 per brick in different parts of Karnataka whereas the cost of a compressed fired clay brick is ₹ 15 per brick.

Cost Estimation of Prepared IOW Bricks

The procedure for cost estimation of prepared IOW bricks is as given below:

The cost of iron ore waste (IOW) was not considered, as the iron ore waste is a waste material for mine owners and is present in abundance in the mine. Similarly, the cost of fly ash was also not considered as it is a waste product generated in thermal power plants. However, the transportation cost of IOW from the mine to NITK was considered and is ₹ 10,000/- and the cost of transportation of fly ash was considered which is ₹ 600/-.
Total bricks prepared = 1800
(Though the total bricks prepared were 1800, for this study only 375 bricks were used)
Fly ash cost (transportation) = ₹ 600/-
IOW cost (transportation cost) = ₹ 10,000/-
Labour cost (two labour) = ₹ 10,800/- (for 18 days @ ₹ 300/day/labour)
Total cost of fly ash, IOW and labour = ₹ 21,400/-
Therefore, cost of one brick = ₹ 21,400 ÷ 1800 = ₹ 11.90
Total amount of cement used in experimentation = 505 kg
Total cost of cement = ₹ 4160/-
Therefore, the cost of cement/kg = ₹ 8.24

Bricks Prepared with 30% Cement

Total No. of bricks prepared using 30% cement = 30
Total amount of cement used for preparing 30 bricks = 15.3 kg
Therefore, amount spent on cement for preparing 30 bricks = ₹ 126.00
Cost of cement incurred on single brick = ₹ 4.20
Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 4.20 + ₹ 11.90 = ₹ 16.10

Bricks Prepared with 25% Cement

Total No. of bricks prepared using 25% cement = 45
Total amount of cement used for preparing 45 bricks = 18.0 kg
Therefore, amount spent on cement for preparing 45 bricks = ₹ 148.30
Cost of cement incurred on single brick = ₹ 3.30
Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 3.30 + ₹ 11.90 = ₹ 15.20

Bricks Prepared with 20% Cement

Total No. of bricks prepared using 20% cement = 60
Total amount of cement used for preparing 60 bricks = 20.4 kg
Therefore, amount spent on cement for preparing 60 bricks = ₹ 168.10
Cost of cement incurred on single brick = ₹ 2.80
Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 2.80 + ₹ 11.90 = ₹ 14.70

Bricks Prepared with 15% Cement

Total No. of bricks prepared using 15% cement = 75
Total amount of cement used for preparing 75 bricks = 17.4 kg
Therefore, amount spent on cement for preparing 75 bricks = ₹ 143.40
Cost of cement incurred on single brick = ₹ 1.90

Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 1.90 + ₹ 11.90 = ₹ 13.80

Bricks Prepared with 10% Cement

Total No. of bricks prepared using 10% cement = 90
Total amount of cement used for preparing 90 bricks = 14.7 kg
Therefore, amount spent on cement for preparing 90 bricks = ₹ 121.00
Cost of cement incurred on single brick = ₹ 1.30
Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 1.30 + ₹ 11.90 = ₹ 13.20

Bricks Prepared with 9% Cement

Total No. of bricks prepared using 9% cement = 20
Total amount of cement used for preparing 20 bricks = 2.97 kg
Therefore, amount spent on cement for preparing 20 bricks = ₹ 24.47
Cost of cement incurred on single brick = ₹ 1.20
Therefore, total cost of preparing one single brick (cement + fly ash + IOW + labour) = ₹ 1.20 + ₹ 11.90 = ₹ 13.10

As can be seen from the above calculation that the cost of IOW bricks prepared with 30% cement, 25% cement, 20% cement, 15% cement, 10% cement and 9% cement comes out to be ₹ 16.10, ₹ 15.20, ₹ 14.70, ₹ 13.80, ₹ 13.20 and ₹ 13.12 per brick (excluding profit) respectively, which is very much comparable with the cost of compressed burnt clay bricks available in the market. In the above calculations profit has been ignored. Further, the mass comparison indicated the average mass of prepared IOW bricks to be around 2.35–2.45 kg, whereas the average mass of commercially available fired compressed brick will be 2.80–2.89 kg.

Conclusions

An attempt has been made in this work to investigate the utility of iron ore waste in preparing non-fired bricks. The bricks were prepared using different combinations of iron ore waste, fly ash and cement. Results of this investigation reveal that iron ore waste can be very well used for preparation of non-fired bricks by mixing it with additives like cement and fly ash. It is concluded that IOW bricks prepared with cement from 9% and above and with 28 days of curing are suitable for brick making and also meet the IS specifications. Results also indicated that bricks with cement content below 9% are not stable once removed from the mould and also do not meet the BIS standards of compressive strength.

The investigation also reveal that the bricks prepared with 30, 25, 20, 15, 10 and 9% cement costs ₹ 16.10, ₹ 15.20, ₹ 14.70, ₹ 13.80, ₹ 13.20 and ₹ 13.12 per brick (excluding profit) respectively. This is very much comparable with the cost of fired compressed bricks available in the market (costing ₹ 15 per brick). As the cost figures arrived in this investigation are based on the cost computation of prepared bricks on laboratory scale, it is anticipated that the cost figures may reduce further when the brick preparation is done on industrial scale.

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