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Development of value added product using iron ore waste for its effective utilization

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A B S T R A C T

India is one of the major iron ore producer and exporter in the world. It was estimated that about 10–15 % of the iron ore mined in India is unutilized, even now, and is discarded as waste/tailings due to lack of cost effective technology in extracting low grade ores. The waste thus created in the form of ultra-fines or slimes has remained a major unsolved and challenging task for the Indian iron-ore industry. Many researchers have worked in this regard for comprehensive utilization of this waste and so as to reduce its effect on the environment. In India there is a significant demand for building materials and it is therefore imperative to use the mining and mineral wastes in the production of bricks, concrete blocks and other value added products. In the present study an attempt has been made to prepare modular bricks using iron ore waste with fly ash and cement as aggregates. Bricks were prepared as per IS standards and tested for its viability for usage in construction industry. The results of the study reveals that mixture with 70 % iron ore waste, 15 % cement and 15 % fly ash gives the minimum required compressive strength and water absorption properties of bricks for minimum curing days.

1. Introduction

India has large reserves of metal-bearing ore and it occupies sixth position in the world with regard to iron-ore reserves. Further, India is one of the important iron-ore producer and exporter in the world too. However, approximately 10–15 % of the iron ore mined in India is unutilized, even now, and is discarded as waste/tailings due to lack of cost effective technology in extracting low grade ores (Rudramuniyappa, 1997). The waste/tailings that are called ultra-fines or slimes are mainly those having diameter of less than 150 µm, and are not regarded to be useful and hence are discarded. In India, approximately 10–12 million tons of such mined ore is lost as tailings. The safe disposal or utilization of such vast mineral wealth in the form of ultra-fines or slimes has remained a major unsolved and challenging task for the Indian iron-ore industry. The cost of handling and storage of mineral waste represents a financial loss to a company, estimated at around 1.5 to 3.5 % of total cost and depending on the mineral being mined (Mohanty, 2010). Therefore, comprehensive utilization of waste/tailings is important in saving resources, improving surrounding and for sustainable development.

1.1. Why mine waste?

There is a significant demand of building materials in India and elsewhere. It is therefore imperative to use the mining and mineral wastes in the production of bricks, concrete blocks and other value added products (Chakravarthi et al., 2007, Muduli et al., 2010). 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. 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 materials for brick construction should be encouraged. Mine wastes and tailings can be converted into bricks, which can meet the demand of bricks in metropolitan cities for the next 30 years or even more. Further, building blocks from mine waste are eco-friendly as it utilizes waste and reduces air, land and water pollution. It is energy efficient and also cost effective as reported by various investigators in the past.

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2. Literature review

Hammond (1998) critically reviewed the use of mining and quarrying waste as building material. The availability, distribution and uses of wastes in many mining countries of the world were discussed. The use of mining waste materials as concrete aggregates for the purpose of construction, production of brick and tiles, cement, pozzolana and pigments for paints were identified. It was stressed that, by using waste materials, natural resources will be conserved, energy will be saved and environmental pollution will be reduced. Rai and Rao (2005) also critically reviewed present status of waste-based building materials available in India. Investigation by Zhang et al. (2006) revealed that comprehensive utilization of iron ore tailing is efficient, socially beneficial and also improves environment situation. Chen et al. (2011a) carried out studies on utilization of hematite tailings in production of non-fired bricks. In their study the tailing bricks were prepared by pressing and curing process, in the presence of cementing material and coarse aggregates. The study showed that non-fired bricks with 78 % hematite tailings can be prepared with 15 % water content at 20 MPa pressure with natural curing in room temperature for 28 days and the compressive strength was achieved up to 15.9 MPa. Zhang et al. (2012) achieved the same result as obtained by Chen et al. (2011a), whereas Chen et al. (2011b) in their study achieved the compressive strength up to 15.9 MPa for 20 days curing. Zhao et al. (2011) studied for possibility of using hematite tailings as main raw material to prepare high strength autoclaved bricks. He demonstrated that 1.2 MPa optimum autoclave pressure and 6 hrs autoclave time could be achieved with optimum mixture of 70 % hematite tailings, 15 % lime and 15 % sand. Ullas et al. (2010) used mine waste as an alternate to the natural river sand for the investigation. The optimum mix proportion of soil, sand and cement were fixed and the sand fraction was replaced by iron ore tailings at 25 %, 50 % and 100 % ratios. The block characteristics were observed and found that considerable amount of sand can be replaced by iron ore tailings without compromising with desirable characteristics of stebilised mud blocks used for masonry. It was also observed that the water absorption increases with increase in iron ore tailings content within the limits. Experimental results of Xiaoqing et al. (2011) reveals that the concrete products obtained by mixing the iron ore tailings, cement and fly ash at a ratio 65:25:10 and with 28 days curing compressive strength achieved was 31 MPa. Aruna and Kumar (2010) investigated on utilization of iron ore tailings in manufacture of concrete paving blocks. Five references mixes of cement, jelly dust, baby jelly are used for the study. Out of ten paving blocks prepared from each type of mix, out of which five specimens were cured for 7 days and five were cured for 28 days. The laboratory tests reveal better compressive strength without much change in water absorption. In this study the highest compressive strength achieved was 36.5 Mpa with highest water absorption of 7.02 %. Roy et al. (2007) carried out an experimental study on gold mill tailings of Kolar Gold Fields in making of bricks. The bricks were prepared using mill tailings with cement as an additive in the proportion of 5 %, 10 %, 15 %, 20 % and 25 % with curing duration of 3, 7, 14 and 28 days and tested as per IS Standards. The results of the study indicates that with 20 % cement for 14 days curing the compressive strength of 36 kg/cm^2 was achieved, which meets the criteria of assessment of brick (Jha, 1992). Further, in all the cases of mixture it was observed that the water absorption was less than 20 %, irrespective of the firing temperature. The water absorption of quality bricks should be less than 20 % after 24 hr of immersion in water (Khanna, 1994). The soil tailing bricks were sun dried and then fired in a furnace at different temperatures and found that mixing of high percentage of mill tailings (more than 70 % of mill tailings) causes deformation problem with black cotton soil (Roy et al., 2007). Similarly cracks were found with red soil after firing hwne percentage was more than 55 %. It was also observed that when the mill contents are lower in percentage, the linear shrinkage of bricks was more than 3 %, and hence it did not satisfy the minimum criteria.

Dean et al. (1996) used the gold mill tailings in addition to fly ash, Portland cement and water to manufacture concrete blocks of size 10.16 cm × 20.32 cm and achieved the average compressive strength of 18.34 Mpa. This is almost 40 % higher than the American Society for Testing and Materials (ASTM) requirements for load bearing block (i.e. 13.10 MPa) and at the same time the bricks made with this material had compressive strength of 28.22 MPa which is 17 % higher than that ASTM requirement. Yonggang et al. (2011) made fired bricks by using of gold tailings and clay, by following the sequence of pre-treatment, mixing, ageing, moulding, drying and sintering. While testing for its performance it was found that the compressive strength can reach the Standard MU10 (Fired Common Brick) when using 70 % to 90 % fine tailings at 1000° C with 60 minutes holding time. Sunil Kumar (2002) developed fly ash-lime-gypsum (Fal-G) bricks and hollow blocks by utilizing industrial waste which was found economical., The mixture along with fly ash at 60 %, 70 % and 80 % ratios was used for bricks of size 220×100×75 mm and hollow blocks of size 150×150×150 mm. The samples were cured for one week using gunny bags by sprinkling water on it and then the samples were transferred to the tank containing sulfate solution which is at temperature of 23±2° C, and later it is cured for 24, 72 and 96 days. The sample prepared with the ratio 80:10:10 (i.e. fly ash: lime: calcined phosphogypsum) was achieved the compressive strength of 5.9 N/mm^2 after 96 days casting/curing, which satisfies IS code (1077:1992) of burn clay bricks (i.e. 3.5 N/mm^2). However, the water absorption of the bricks varies from 28.9 % to 37.2

% which does not satisfy the IS standards i.e. water absorption should not be more than 20 % (by weight).

3. Laboratory investigation

As a case study a large mechanized iron ore mine has been identified and waste samples were collected from three different locations and chemical analysis was carried out by using coning and quartering method to collect representative sample and chemical analysis was carried out using digestion method, photometric method and by Scanning Electron Microscopic (SEM) method as shown in Fig. 1, 2 and 3, respectively. During chemical analysis of samples it was found that at two locations Fe content is more than 30 % and hence these samples were not considered for preparation of bricks.

Fig. 1: Chemical analysis by digestion method

Fig. 2: Chemical analysis by photometric method

Fig. 3: Chemical analysis using scanning electron microscope

Table 1 indicates the results of chemical analysis by digestion and photometric method whereas Table 2 indicates results of SEM method. As shown in Table 1 and Table 2. Samples 2 and 3 are having Fe content more than 30 % and hence only sample 1 was considered for preparation of bricks.

Table 1: Results of chemical analysis by digestion and photometric method

Parameters	Sample 1	Sample 2	Sample 3
SiO_2	40.70	21.196	38.80
Fe_2O_3	22.93	58.88	32.08
Al_2O_3	22.27	2.2976	30.45
CaO	4.79	5.3977	6.5219
MgO	0.19	0.0213	0.090
Na_2O	0.0332	0.1494	0.1217
K_2O	0.0542	0.0723	0.1385

Table 2: Results of chemical analysis using SEM

Parameters	Sample 1	Sample 2	Sample 3
SiO_2	42.43	36.49	26.45
FeO	19.75	31.29	47.33
Al_2O_3	33.94	29.99	24.90
CaO	0.26	0.07	0.23
MgO	0.74	0.56	0.41
Na_2O	0.24	0.57	0.07
K_2O	1.81	0.57	0.36
TiO_2	0.82	0.47	0.24

Sieve analysis was also carried out using mechanical sieve shaker machine. Table 3 gives the result of sieve analysis and Fig. 4 shows the respective graph plotted for cumulative percentage retained in the sieve Vs sieve size.

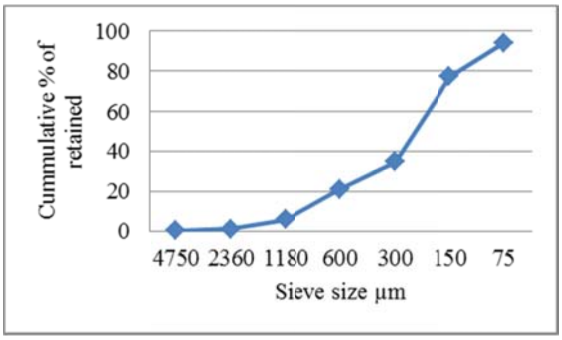

Fig. 4: Graph showing cumulative % retained Vs sieve size

4. Preparation and testing of bricks

For preparing the bricks, iron ore waste was taken as a major aggregate in combination with fly ash and cement as minor aggregates. It is a known fact that fly ash is safe to use, stable under different conditions and its physical and chemical properties are intact (Zhang et al., 2012).

Table 4 gives the chemical composition of fly ash which is used in the present study the bricks were prepared using cast iron moulds for five different combinations of above said aggregates (i.e. cement, fly ash and iron ore waste) by percentage of weight as given in Table 5. The bricks were of size 190 mm × 90 mm × 90 mm (BIS, 1988; 1993; 1989). It was calculated that for a single brick 2.65 kg of mixture is required and sufficient amount of water i.e. about 600 ml for each brick was added while mixing. Oil was applied to the inner part of the mould and prepared mixture is poured slowly into it so that it spreads evenly inside the mould.

Table 3: Results of sieve analysis

Sieve size (µm)	Retained Weight (gm.)	Passing weight (gm.)	Retained (%)	Cum. retained (%)	Cum passing (%)
4750	1.2	498.8	0.24	0.24	99.76
2360	3.2	495.6	0.64	0.88	99.12
1180	24.42	471.18	4.884	5.764	94.236
600	76.96	394.22	15.392	21.156	78.844
300	67.82	326.4	13.564	34.72	65.28
150	211.8	114.6	42.36	77.08	22.92
75	85.8	28.8	17.16	94.24	5.76
-75	28.8	0	5.76	100	0

After filling the mixture, load up to 15-18 kN was applied using compression testing machine for proper compaction of bricks. Fig. 5 shows bricks inside the moulds. The bricks thus prepared was kept for 24 hours in the mould and then removed and kept under sunlight for drying with proper curing by spraying water, as shown in Fig. 6. Bricks were cured for 7 days, 14 days, 21 days and 28 days and then tested for its compressive strength using compression testing machine. Fig. 7 shows the brick under compression test. Fig. 8 shows the failure plane of brick after compression test. Similarly water absorption test was also carried out as shown in Fig. 9.

Table 4: Chemical composition of fly ash

LOI (%)	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

Fig. 5: Mixture filled in brick moulds

Fig. 7: Compression testing machine

Fig. 6: Bricks are kept for curing process

Fig. 8: Failure planes after compression

Fig. 9: Water absorption test

5. Results and discussion

In total five set of bricks were prepared with different ratio of cement (C), fly ash (FA) and iron ore waste (IOW), which are designated as Ratio - A, Ratio - B, Ratio - C, Ratio - D and Ratio - E as mentioned in Table 5. For each ratio of mixture 40 bricks were prepared and every ten set of bricks were cured for 7 days, 14 days, 21 days and 28 days. Out of ten bricks five bricks were tested for its compressive strength and five for its water absorption, as per ISRM standards (BIS 1980). Table 5 also gives the results of compressive strength and water absorption for all the five set of bricks of different ratio.

According to IS standards, the compressive strength of bricks should be minimum 3 MPa, whereas water absorption should not be more than 20 % for 24 hr immersion (BIS, 1991; 1992) From Table 4 it can be concluded that the compressive strength of bricks reduces with 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.

Table 5: Results of compressive strength and water absorption

Mix Ratio	No. of Curing Days							
	7	14	21	28	7	14	21	28
	Compressive Strength (MPa)				Water Absorption (%)			
30:00:70 C:FA:IOW (Ratio A)	8.58	8.82	11.30	11.52	14.50	8.75	6.70	5.46
	7.50	8.71	11.25	11.43	14.55	8.78	6.74	5.48
	7.97	8.77	11.14	11.75	14.45	8.80	6.72	5.50
	7.60	8.75	11.20	11.58	14.55	8.82	6.80	5.45
	7.75	8.80	11.28	11.65	14.50	8.84	6.78	5.46
30:05:70 C:FA:IOW (Ratio B)	5.87	7.55	7.54	8.67	13.90	8.78	6.66	5.44
	5.95	7.38	7.72	8.65	13.80	8.75	6.64	5.40
	5.71	7.29	7.61	8.74	13.75	8.72	6.68	5.42
	5.80	7.45	7.59	8.70	13.60	8.76	6.62	5.40
	5.78	7.50	7.65	8.69	13.70	8.74	6.66	5.45
20:10:70 C:FA:IOW (Ratio C)	4.33	5.37	6.38	6.96	13.55	8.68	6.60	5.40
	4.74	5.45	6.92	6.85	13.60	8.70	6.58	5.36
	4.63	5.25	6.67	7.12	13.50	8.72	6.56	5.38
	4.70	5.36	6.70	6.90	13.45	8.70	6.60	5.34
	4.55	5.40	6.75	6.88	13.58	8.67	6.55	5.38
15:15:70 C:FA:IOW (Ratio D)	3.39	4.53	4.14	4.37	12.90	8.62	6.52	5.34
	3.08	4.27	4.06	4.58	12.85	8.64	6.50	5.38
	3.21	4.40	4.21	4.44	12.80	8.60	6.48	5.36
	3.17	4.35	4.18	4.50	12.95	8.58	6.46	5.38
	3.10	4.40	4.15	4.48	12.85	8.60	6.44	5.30
10:20:70 C:FA:IOW (Ratio E)	2.90	2.95	3.02	3.10	12.85	8.56	6.40	5.28
	2.63	2.54	3.03	3.09	12.95	8.54	6.42	5.30
	2.79	2.70	2.90	3.23	12.90	8.50	6.38	5.26
	2.75	2.65	2.95	3.20	12.85	8.52	6.40	5.24
	2.65	2.84	3.05	3.15	12.90	8.50	6.42	5.28

6. Conclusion

It is a general phenomenon that the compressive strength of bricks increases with increase in percentage of cement as well as with increase in curing period. The present study demonstrates that the mixture with 70 % iron ore waste, 15 % cement and 15 % fly ash gives the minimum required compressive strength and water absorption properties of bricks for minimum curing days i.e. for 7 days curing. The addition of fly ash also helps in reduction of weight of bricks and also improves the binding property of mixture. The bricks thus prepared would be economical compared to laterite or hollow concrete bricks/blocks available in the market. Further, it also facilitates utilization of waste spreading over large area in and around the mines and also helps in improving aesthetic beauty of the surroundings.

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