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Compressed stabilized earth blocks using iron mine spoil waste - An Explorative study

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Abstract

Iron being a basic raw material for iron and steel industry, mining of iron ore has become a very important economic activity in many countries including India. One of the various adverse effects of mining to the surrounding environment near mining area is piling up of overburden dumps, leading to difficulty of disposal of the waste. For sustainable development, various researchers have tried to utilize different types of industrial by-products like fly ash, blast furnace slag, sewage sludge, marble dust, and the like in the preparation of stabilized blocks. In a similar way, comprehensive utilization of mining waste is important in saving resources, improving surroundings of mining area and also leading to sustainable development. With an intention of finding a possible solution for the bulk utilization of the Iron Mine Spoil Waste (MSW) accumulated as silt in the upstream portion of an earthen dam located in one of the mining area in Sandur region, Karnataka, India, an exploratory study was taken up to prepare CSEBs utilizing various proportions of MSW, quarry dust and stabilizers (Cement and lime). Attempts made in this study to utilize MSW in preparation of CSEBs with varying amounts of MSW (30 % to 50%), cement and lime have shown that wet compressive strength of blocks to be more than 5 MPa at 6 months of ageing. This value of wet compressive strength is good enough for residential buildings. The present study brings out green building blocks suitable for construction and thereby promote sustainability.

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Keywords: Stabilization; building blocks; mine spoil waste; sustainability; waste mangement

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Nomenclature

CSEBs - Compressed Stabilized Earth Blocks

1. Introduction

For the economic progress of any country, mineral resources are very essential, and hence, mining has become a very important activity. Iron is the second most abundant metallic element in the earth crust accounting for 5.6 % of the lithosphere [1]. World resources of Iron Ore are estimated to exceed 800 BT of crude ore containing more than 230 BT of iron. India is one of seven largest producers in the world along with Australia, Brazil, China, Russia, Ukraine and USA [2].

India is endowed with fairly large reserves of iron ore which are of moderate to good quality for its domestic requirement as well as for export [3]. In India, the major deposits of iron ore are located in the states of Jharkhand, Orissa, Chattisgarh, Karnataka and Goa, of which 60% of hematite ore deposits are found in the Eastern sector and about 80% magnetite ore deposits occur in the Southern sector, especially in Karnataka (GSI, 2006) [1]. Karnataka state is endowed with approximately 9.03 BT of Iron ore, which is about 41% of India's estimated total hematite and magnetite iron ore resource (IBM, 2005) [4, 5].

Similar to any of the human activities, mining operations also produce waste materials. "Waste" is a general term for material which currently has little or no economic value [5,6]. Mining of any mineral ore can result in a number of adverse effects on the environment and affect air, water, land, flora & fauna, thus causing ecological imbalance in the surrounding regions. One such effect would be piling up of overburden dumps obtained during the process of ore extraction owing to which huge piles of mine wastes are found in and around mining areas. The waste/tailings that are ultra fines, with the particle size less than 150 microns, are not useful, and hence, discarded. In India approximately 10 – 15 % of the iron ore mined is unutilized and is discarded as waste due to lack of cost effective technology in extracting low grade ores. Safe disposal or utilization of such vast ultra fines mineral waste has remained a major unresolved issue and challenging task for the Indian iron ore industry in particular and society at large. Though the mining industry plays a leading role in waste management, and it is one of few industries that recycles its own waste [7], yet the problem of proper reuse of waste from ore mining needs to be addressed.

For sustainable development, there is a need to explore utilizing industrial by-products or wastes generated by similar activity like ore mining, which are easily available and also needing proper disposal. Lottermoser [8] reports the various possible options for reuse and recycling of mining, processing and metallurgical wastes accumulating at mine sites. Few researchers have tried to utilize Iron Ore Tailings (IOT) in the preparation of conventional fire burnt bricks [9, 10]. However, preparation of burnt bricks is energy intensive, and hence, few attempts to prepare stabilized blocks using IOT, have been tried by researchers as reported in the literature [11, 12]. However, the composition of IOT used in making stabilized blocks are essentially of sand and silt composition, which may not be case in all the type of iron mine waste. Therefore, the authors of this study felt a need to explore the possibility of preparing stabilized blocks utilizing the mine spoil waste deposited in one of the water body, namely Ankamanahal dam, Sandur region (one of the mining region in Karnataka state) which was more clayey in nature with high plasticity. This would provide building blocks to be used in construction applications, and also make it competitive as compared with common burnt clay bricks. This paper reports the part of the research attempts done to utilize iron mine spoil waste in the preparation of good quality and durable building blocks.

2. Background information

The western and south-western part of Bellary district of Karnataka, India is a hilly terrain where iron ore is found to occur, mostly in the hill tops and slopes. Sandur – Hospet region of this district has abundant reserves of Iron ores from which large amount of fines are generated during the process of mining, crushing and screening the ore. Nearly 50-60% of the total burden removed is finer than 10mm size and these fines are dumped at mine sites as waste. There is no systematic plan in preserving these fines. During the rainy season, these fines are carried by runoff water. Ultimately, the silt and suspended matter transported by the running water gets deposited into the nearby tanks and reservoirs, which are storage bodies of the region [5, 13]. Ankamanahal dam is one such storage body in the Sandur region where mining activity is rampant. Silting in the upstream portions of this dam has

occurred over a period of many years, slowly reducing its storage capacity. When flash flood occurred in August 2011, this dam could not accommodate the water coming from the catchment area to the storage area because of the continuous deposition of mine spoil waste in the upstream portion of the dam taken place over a period of many years. As a result of this, the dam got breached and failed to perform its intended purpose (Fig. 1). With a proposal to construct a new dam at the same location, a need arose to remove the silted mine spoil waste (MSW) and thereby restore the storage capacity of the reservoir to facilitate the construction of new masonry dam. As a part of geotechnical consultancy work, the officer in-charge approached the first author, and in the process of discussion, the officer requested for a feasible solution to utilize the huge quantity of mine spoil waste deposit which needs to be removed for desilting the storage area. The detailed sub-soil exploration revealed that a uniform deposit of mine spoil waste was present for an average depth of 10 m along the proposed length of the dam. This deposit extended to a considerable distance upstream of the breached dam section. Based on this information, an exploratory study was taken up with an intention to explore the possibility of utilizing the iron mine spoil waste which was collected in the upstream side of Ankamanahal dam to prepare Compressed Stabilized Earth Blocks (CSEBs).



Fig. 1. View of breached portion of Ankamanahal dam during August 2011



Fig. 2. Collection of Iron MSW from upstream portion of Ankamanahal dam site, Sandur region, Karnataka, India

3. Methodology

3.1. Materials and methods

For studying the possibility of utilizing Iron Mine Spoil Waste (MSW) in the preparation of Compressed stabilized blocks, MSW was collected from Ankamanahal dam site (Fig. 2). Since the MSW used in this study was completely passing through 75 μm I.S. sieve (Fig. 3), and certain amount of frictional material in the form of Sand is generally required in the preparation of CSEBs to achieve requisite strength and also be durable as a building block in masonry construction, there was a need to blend MSW with certain amount of frictional material to make it suitable for making blocks. Due to the increasing demand and cost of river sand, it was desired to try an alternative frictional material, which is easily available and less costly compared to river sand. Since quarry dust is a frictional material, usually having a particle size distribution quite similar to river sand, it was used in the preparation of blocks as a replacement to sand, and also to make the blocks economical. Quarry dust was obtained from a locally available commercial vendor. Admixtures used in the preparation of blocks were Ordinary Portland cement (OPC) of 53 grade and lime.

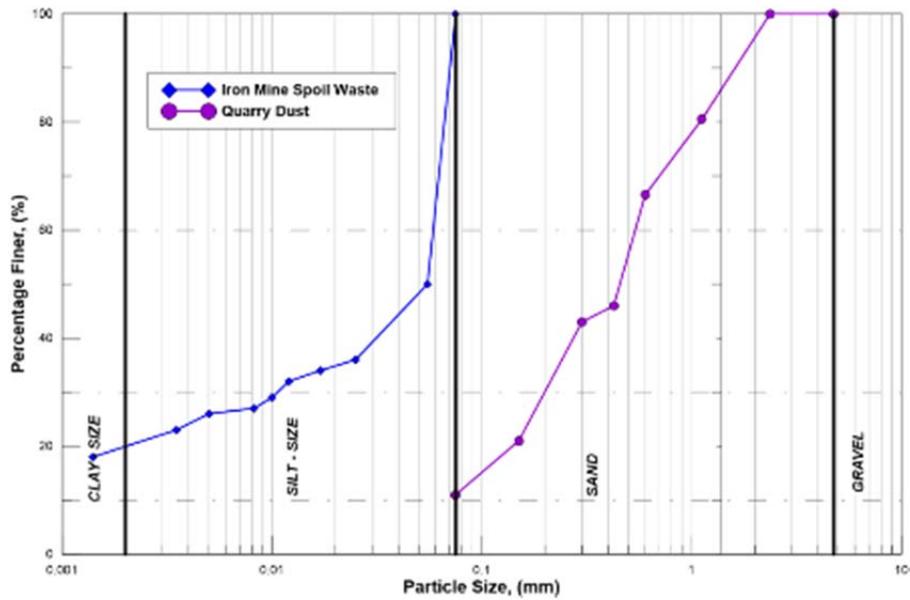


Fig. 3 Grain size distribution of Iron mine spoil waste and quarry dust used in the study to make CSEBs



Fig. 4. Preparation of MSW by rolling to break lumps



Fig. 5 Typical view showing weighed portion of various constituents used in the preparation of CSEB

3.2. Methods

The MSW obtained was sun dried by spreading on level paved surface, and later pulverized to break the clods by using a roller (Fig. 4). Later using quartering technique, the sample was mixed to obtain homogeneity in the source material. This was later stored in drums for making blocks. Three set of samples from the homogeneous MSW stored in drums were selected, and independently characterized for determining the physical properties namely, liquid limit, plastic limit, shrinkage limit, particle size distribution, and specific gravity using the standard procedures as specified by SP-36 (Part1)-1987 [14], and the average values of the results obtained are reported in Table 1. Quarry dust was tested for its specific gravity and particle size distribution, and the results are also reported in Table 1.

Table 1. Physical properties of Iron mine spoil waste and quarry dust used in the preparation of CSEBs in this study [12]

Sl. No.	Material	$G_s^{\#}$	w_L (%)	w_P (%)	w_S (%)	Grains size distribution (%)			
						Gravel	Sand	Silt (size)	Clay (size)
1.	Iron mine spoil waste	2.80	53	40	39	0	0	79	21
2.	Quarry dust	2.75	-	-	-	0	89	11	0

G_s – Specific gravity; w_L – Liquid limit; w_P – Plastic limit; w_S – Shrinkage limit

A sample of Iron mine spoil waste was chemically characterized at M/s Essen & co., Malleshwaram, and Bangalore. The test results are presented in Table 2. From the table it can be observed that the source material mainly consists of silica (32%), alumina (21%) and iron oxide (33%). It can be further observed that sufficient quantity of silica and alumina (more than 50 %) are present in the iron mine spoil waste, so, it was considered to be a suitable material for making stabilized blocks, as the particles would chemically react in the presence of suitable stabilizers like lime and cement to form cementitious gels, namely, silicates and aluminates [12].

Table 2. Chemical composition of mine spoil waste [12]

Sl. No	Parameters	Quantity (%)
1	Silica (SiO_2)	32.27
2	Alumina (Al_2O_3)	21.37
3	Ferric oxide (Fe_2O_3)	32.73
4	Titanium dioxide (TiO_2)	1.26
5	Calcium oxide (CaO)	0.00
6	Magnesium oxide (MgO)	0.00
7	Sodium oxide (Na_2O)	0.25
8	Potash (K_2O)	0.905
9	Manganese oxide (MnO)	0.02
10	Loss on Ignition (LOI)	11.13

4. Experimental program

4.1. Proportioning of soil-admixture mix

As a first step to explore the possibility of utilizing mine spoil waste in the preparation of masonry blocks, three variations of MSW, namely 30, 40 and 50 % were used. Since there is advantage of using lime in some combination with cement in the preparation of CSEBs as recently reported by Sravan and Nagaraj [15], Nagaraj et al. [16], and Nagaraj et al. [17], cement and lime were used in combination in two variants, namely, 8 % (6% cement + 2 % Lime); and 10 % (8% Cement + 2 % Lime) in the preparation of blocks. The various combinations of mine spoil waste, quarry dust and admixtures which were chosen for the six series of blocks is presented in Tables 3. Sufficient number of CSEBs were prepared to study the time effects on the compressive strength and water absorption. The selected time intervals for this ageing effects of stabilizers on the compressive strength and water absorption of CSEBs were 7, 15, 30, 60 days and 6 months. Flexure test was conducted on the blocks after one month of ageing.

Table 3 Proportion and combination of stabilizers, Iron mine spoil waste and quarry dust used in the preparation of CSEBs

Series	Cement (%)	Lime (%)	Iron Mine spoil waste (%)	Quarry Dust (%)
1a			30	62
1b	6	2	40	52
1c			50	42
2a			30	60
2b	8	2	40	50
2c			50	40

4.2. Preparation of blocks

The procedure described in this section is similar to that reported by Shirisha (2013) [5] and Nagaraj et al [17]. Blocks were prepared using Mardini press to give a block size of 230 x 110 x 75 mm. The preparation process comprised of batching, mixing, placing the mix in the press, compaction and ejection of the blocks. The blocks were prepared to a density of 2.05 Mg/m³. Required quantities (mass basis) of the ingredients namely, MSW, quarry dust and stabilizers (lime and cement) as obtained from the calculations depending on the series were weighed (Fig. 5) and initially mixed in a dry condition. This was later spread on a big tray; to which calculated quantity of water was sprinkled to the mix and thoroughly worked with hand for 2 to 3 minutes to have uniform distribution of moisture. Then the wet mix was transferred to the mould placed in position on the Mardini press. Wet mix was remoulded in the mould using a wooden mallet to give proper placement. The lid of the mould was closed and properly locked at the top. Using the toggle lever mechanism, the mix was pressed to give the designed compactive effort. The soil block was ejected from the mould by opening the top lid (Fig. 6). The ejected block was weighed and serially stacked (Fig. 7) and subsequently labeled with date of preparation, date of testing and a suitable identification number for ease of future identification based on the series adopted. It was ensured to wet cure the blocks by covering the blocks with gunny bags and spray with sufficient water to keep them moist for a minimum period of 28 days (Fig. 8). Sufficient number of CSEBs were prepared for evaluating their engineering properties, namely, wet compressive strength and water absorption for various ageing periods, namely, 7, 15, 30, 60 days and 6 months from the date of preparation; and flexure test after one month of ageing.



Fig. 6. Freshly ejected CSEB with MSW from Mardini press



Fig. 7. Stacking of freshly prepared blocks



Fig. 8 View showing curing of blocks



Fig. 9 View showing soaking of CSEBs in water before testing

4.3. Testing of blocks

Blocks were tested for determining their wet compressive strength and water absorption at different periods of ageing reckoned from the date of preparation. The tests were carried out as per the prescribed procedures of Bureau of Indian Standards. The results in this study are an average of test conducted on five blocks at each period of ageing.

Wet compressive strength of the blocks was determined according to Bureau of Indian standards [IS: 3495-1, 1992] [18]. Each block was prepared by filling the frog marks on the faces by 1:1 cement mortar and was cured for a day. Subsequently the blocks were immersed in clean water for 2 days in advance before the date of testing corresponding to ageing selected in the study (Fig. 9). The blocks were later removed from water, and the surfaces were wiped dry and tested for their compressive strength using Universal Testing Machine (UTM). The load was applied at the rate of 2 N/mm²/min. Plywood sheets of 3 mm thick was placed on either faces of the block before the application of load (Fig. 10).

Water absorption on CSEBs was done as per Bureau of Indian standards [IS: 1725, 2013] [19]. The blocks were dried completely in the oven and their mass was recorded accurately. The blocks were then immersed in water for 24 h. Later, the blocks were weighed again, and the increased mass was noted to determine their water absorption.



Fig. 10 Wet compression test on block



Fig. 11 Flexure test on block

Flexural test on blocks at an ageing period of one month was conducted adopting a similar procedure as outlined by ASTM C 67-02c [20] (Fig. 11).

5. Results and discussions

5.1. Wet compressive strength of blocks

Fig. 12 shows the plots of wet compressive strength versus ageing period respectively for blocks of all the six series prepared in this study. From the plots, it can be observed that there is an increase in wet compressive strength of the blocks with ageing. Further, it can be observed that the wet compressive strength of blocks for any combination of admixtures is more for blocks prepared with 40 % MSW. Therefore, it appears that there is an optimum content of MSW that can be used in the preparation of blocks. The values of compression strength of blocks have shown to have an increased rate after 30 days of ageing. This may be because lime is slow to react and impart strength, so, lime used along with cement to stabilize the blocks might have started imparting strength after 30 days as observed from the sudden increase in slope of the plots after 30 days of ageing (Fig. 12). Similar increase in strength after 40 to 50 days of ageing due to the presence of lime along with cement has been recently reported by Nagaraj et al [17]. Blocks prepared using 10 % admixtures have attained the minimum wet compressive strength of more than 3.5 MPa at 60 days of ageing, which is the minimum value of block strength for it to be used as a masonry unit (IS: 3495-part1-1992) [18], whereas blocks prepared with 8 % of admixtures have attained this minimum value of 3.5 MPa after 120 days of ageing. Hence, from these results, it can be observed that blocks having higher percentage of fines than 15 %, it is advisable to use 10 % admixtures to attain desirable value of strength for it to be suitable as a masonry unit in construction.

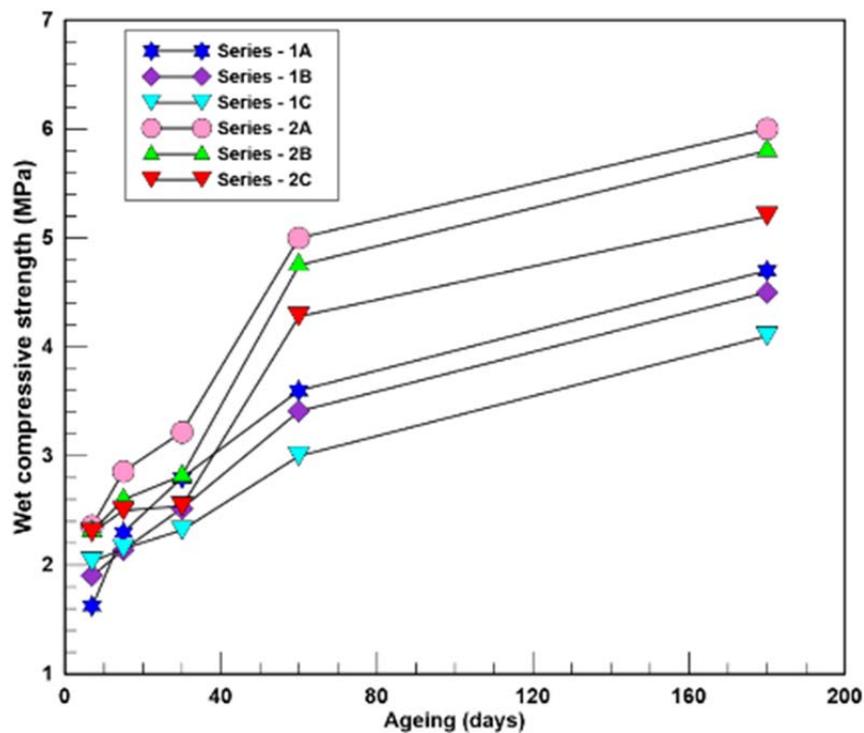


Fig. 12 Wet compressive strength versus ageing for CSEBs prepared with different combinations of MSW and admixtures.

5.2. Water absorption

Fig. 13 show the plots of water absorption with ageing for blocks of all the six series prepared in this study. It can be observed that there is a continuous decrease in the water absorption with ageing. Further, at the end of 30 days of ageing, the values of water absorption are less than 15 %, which satisfies the codal requirement as suggested by IS: 1725-2013 [19]. With further ageing these values will reduce due to the continuous binding reactions taking between the cementitious gel from the admixtures and the soil particles leading to the reduction in the interconnectivity of pores.

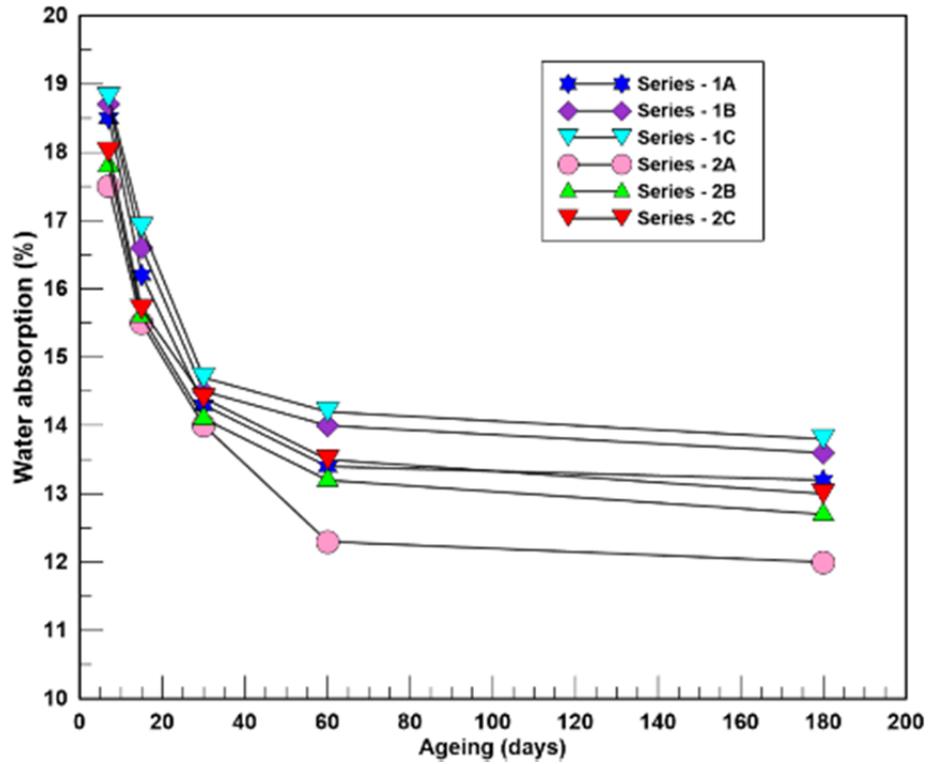


Fig. 13 Water absorption versus ageing for CSEBs prepared with different combinations of MSW and admixtures.

5.3. Flexural strength

Blocks prepared with different mix proportions of MSW, quarry dust and admixtures were tested for the flexural strength at 28 days of ageing, and the results have been summarized in Table 4. The results show that the values of flexural strength are quite good for any block to be suitable to bear the handling stresses during construction, and also to bear load in masonry structures.

Table 4 Flexural strength of CSEBs prepared with MSW after 30 days of ageing

Series	Flexural strength (MPa)
1	0.77
2	0.94
3	0.74
4	1.12
5	0.98
6	0.83

6. Conclusions

Preliminary test results on blocks prepared utilizing iron mine spoil waste in three proportions along with quarry dust and admixtures, namely cement and lime in combination have shown to give blocks of reasonably good engineering properties, which are suitable for construction applications. The wet compressive strength and water absorption values have shown to meet the requirements of a good building block as per Indian standard code of practice; and the flexural strength of blocks are quite good for a block to sustain handling stresses during the stage of transportation to the site and construction of structure. This indicates that these blocks can be effectively used as eco-friendly blocks in construction activity. This also encourages a more detailed study to understand the long-term strength gain and also durability. This would pave way for improvisation for a large-scale utilization of MSW in the preparation of blocks needed for construction industry, and thereby promote sustainability.

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