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Original Article

Coal Mine Overburden As Resource Material For Making Brick

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Abstract - *The coal mine's overburden (CMOB) waste rock consists mainly of sandstone and shale. Among these two, sandstone predominates. Sandstone found with coal seam is generally argillaceous, and hence sand and cementing materials, which are clay minerals, can be easily segregated by simple crushing and washing. An attempt to utilize CMOB clay separated from overburden is made. Three types of mixes of sand and clay are used for the preparation of compressed stabilized earth brick (CSEB) specimens by varying clay and sand percentages. Tests were conducted on these bricks for determining the important parameters influencing the quality of brick viz. dry density, compressive strength both dry and wet, water absorption, and weathering tests.*

The CSEB brick specimens were prepared with pure CMOB clay and stabilized with 8% and 10% Portland cement. The average density of the CSEB specimens fabricated with different mixes is found to vary between 1705 kg/m3 to 2142 kg/m3, respectively. Due to the poor texture of CMOB clay, the water absorption and weight loss due to alternate wetting and drying of the brick were found very high. The texture of CMOB clay is improved for the production of CSEBs, by blending it with 57% of CMOB sand. As the texture of the CMOB clay is improved, both the dry and wet compressive strength of the CSEB specimens also improved significantly. The water absorption of the specimens prepared with Clay:Silt: Sand ratios of 22:60:18 and 19:53:28 exceeded the limit prescribed in the code, whereas the water absorption of the specimen prepared with Clay:Silt: Sand ratio of 09:26:65 is found well within the limit. The tests also exhibited that the weight loss due to abrasion from the wire brush significantly reduced with improvement in the texture of the soil mixes.

Keywords - *Compressed stabilized earth brick (CSEB), coal mines overburden (CMOB), mine waste utilization.*

I. INTRODUCTION

Coal is the prime source of energy in India. It is a sedimentary type deposit. Coal in India is mined either by the opencast method or by the underground method. The opencast method is a dominant method and accounts for more than 90% of the total coal produced in India. In opencast mining, overburden (waste rock) is removed to access the coal seam (Dash, 2019). Once the coal seam is exposed, it is mined out, and the overburden is backfilled in the mined-out area. The excess overburden (nearly 20%) is stacked near pit boundaries as external dumps. External dumps demand not only precious land but also are serious threats to the environment and safety. The amount of waste rock (overburden) generated is increasing year by year due to the increased demand for coal and the increasing stripping ratio. Earlier, the Deposits with a stripping ratio of less than 2 were only mined by the open cast method, and now the open cast mines are being planned for a stripping ratio as high as up to 15 (Das & Choudhary, 2013).

The overburdened waste rock consists mainly of sandstone and shale. Among these two, sandstone predominates. The percentage of sandstone may be as high as up to 85% of the total volume of the waste rock generated (Verma & Deb, 2006). Sandstone is the rock formed by cementing of sands composed largely of quartz and silicate minerals. The cement that binds the clasts may be argillaceous, calcareous, siliceous, or ferruginous (Singh, 1997). Sandstone found with coal seam is generally argillaceous, and hence sand and cementing material can be easily segregated by simple crushing and washing. Authors have successfully separated sand from the coal mine overburden (CMOB) sandstone. Almost 80% of waste separated can be classified as sand, which can be used in concrete or mortar. The rest, 20% overburden, can be classified as clay and has the potential to be used in brick making (Figure 1).

Fig. 1 Overburden, CMOB Clay and CMOB Sand

On the basis of the manufacturing, method bricks can be classified as extruded brick, molded brick (burned brick), and compressed stabilized earth brick (CSEB). CSEB has many advantages over the other two types of bricks, such as the use of local materials, in situ production, good strength, insulation, and thermal properties, the requirement of less-skilled labor & use of local labor, reduction in transport cost, fast & easy construction and generation of the local economy as against bricks made from other building materials (Riza et al., 2010; Guillaud, H., 1995)). It also makes quality housing available to more people and has the ability to absorb atmospheric moisture resulting in a healthy environment inside the building for the occupants. A striking difference between CSEB and burned brick is lower energy consumption during the production process and, as such less carbon emission. CSEB produces a mere 22 kg of CO2/tonne as compared to that of concrete blocks (143 kg of CO2/tonne), common fired clay bricks (200 kg CO2/tonne), and aerated concrete blocks (280-375 kg CO2/tonne) respectively (Mortan, 2008). CSEB products are environment friendly and sustainable because they utilize the almost unlimited resource in their natural state that involve no pollution and negligible energy consumption, thereby benefiting the environment further through saving of biomass fuel (Shahidan et al. 2016; Adam et al. 2001)

Chemically, the clay separated from CMOB is found suitable for making both burnt bricks and CSEB; but texturally, it is found unsuitable for making both burnt bricks and CSEB as the CMOB clay contains a high proportion of silt and less amount of sand. Hence additional CMOB sand can be added to this clay to improve the texture.

In this paper, an attempt to utilize CMOB clay separated from overburden is made. The 20% clay rest after separation of sand from overburden is used for manufacturing CSEB bricks. Three types of mixes are used for the preparation of CSEB specimens by varying clay and sand percentages. The first mix contained 100% CMOB clay. In other Two mixes of CMOB clay were blended with the CMOB sand to improve its texture. The texture of the soil has a controlling influence on the strength and durability of the CSEBs. The IS code 1725- 2013 recommends that a soil for making CSEB should have clay fraction (<0.002 mm) 5-18%, silt fraction (0.002 – 0.075 mm) 10-40%, sand fraction (0.075 – 4.75 mm) 50-80% and gravel fraction (4.75 – 6 mm) 0-10%. Auroville Earth Institute recommends a soil having clay 20%, silt 15%, sand 50%, and gravel 15% for production of CSEBs.

Later tests are conducted on these bricks to determine the important parameters influencing the quality of the brick. Based on the literature survey and IS code:1725-2013, it was decided to conduct compressive strength both dry and wet, water absorption and weathering tests on the specimens prepared. The dry density of the blocks was also determined. Except for compressive strength tests, all other tests were performed on three specimens for each soil mix. Compressive strength tests were performed on five specimens for each soil mix.

II. EXPERIMENTATION

The specimens were prepared with three types of mixes of CMOB clay; pure CMOB clay, 88% CMOB clay blended with about 12% of CMOB sand finer than 150 microns, and 43% CMOB clay blended with 57% whole CMOB sand, hereafter referred to as soil mix A, soil mix B, and soil mix C respectively. By blending 12% of fine sand, the texture of the CMOB clay was marginally improved in soil mix B to 19% clay, 53% silt, and 28% sand. In soil mix C, having 43% CMOB clay and 57% CMOB sand, the clay, silt, sand content was improved to 09%, 26%, and 65%, respectively. Since the plasticity index of the CMOB clay was found to be 12.85, it was decided to use OPC-43 grade confirming the IS 8112-1989 for stabilizing the soil mix A, B, and C. Two mixes were prepared for each soil type. First with 8% and another with 10% of OPC. The details of the mix prepared are given in table 1. The mixes are designated by two characters, and the first character indicates the type of soil mix, and the second character indicates the percentage by weight of cement.

Table 1 Details of the mix used for the preparation of specimens

Mix	Cement (kg)	CMOB Clay (kg)	Whole CMOB Sand (kg)	CMOB Sand Finer Than 150 Micron (kg)	Final texture Clay: Silt:Sand	Water (kg)	Total Quantity of Mix (kg)	Cement Percentage by Weight (%)	Water Cement Ratio
A8	0.48	4.80	0	0	22:60:18	0.72	6.0	8%	1.5
A10	0.60	4.68	0	0	22:60:18	0.72	6.0	10%	1.2
B8	0.48	4.22	0	0.58	19:53:28	0.72	6.0	8%	1.5
B10	0.60	4.12	0	0.56	19:53:28	0.72	6.0	10%	1.2
C8	0.48	2.06	2.74	0	09:26:65	0.72	6.0	8%	1.5
C10	0.60	2.01	2.67	0	09:26:65	0.72	6.0	10%	1.2

IS code 1725 – 2013 prescribes six modular sizes for CSEBs as follows:

Sr. No.	Length (mm)	Width (mm)	Height (mm)
1	290	90	90
2	290	140	90
3	240	240	90
4	190	90	90
5	190	90	40

The study was conducted on small-scale specimens (Figure 2). The specimens were prepared at 50% reduced dimension of the CSEB mentioned against entry 4 in the above table, which is also the modular dimension for burnt bricks. This was done to maintain the aspect ratio of the specimens the same as of the CSEB mentioned against entry 4 in the above table. A compression molding machine, which was based on the screw jack technique, was specially fabricated for making the specimens.

A wooden mold having an internal dimension of 95 mm (l) x 45 mm (w) x 150 mm (h) was prepared. The top and bottom of the mold were kept open. The bottom platen of the machine was fixed in such a way that it could not move up & down but could be removed by moving horizontally. The top platen was made movable up & down by a jack screw system. A lid was made of a thick plyboard of a dimension slightly less than the dimension of the mold so that it could move inside the mold freely and can compress the soil mixes in the mold from the top while tightening the jackscrew. Compaction pressure was estimated by measuring the change in the volume (height) of the CMOB clay filled in the mold. Change in the volume of the CMOB clay-filled in the mold was correlated with applied load by placing the mold in a hydraulic compression testing machine. The mold was filled with the loose mix, and compression force was applied and increased gradually; the change in the height of the mix in the mold was measured at a fixed increment of applied load, and a relationship curve was plotted between the two variables, which is presented in Figure 3.

Fig. 2 Bricks made from CMOB clay

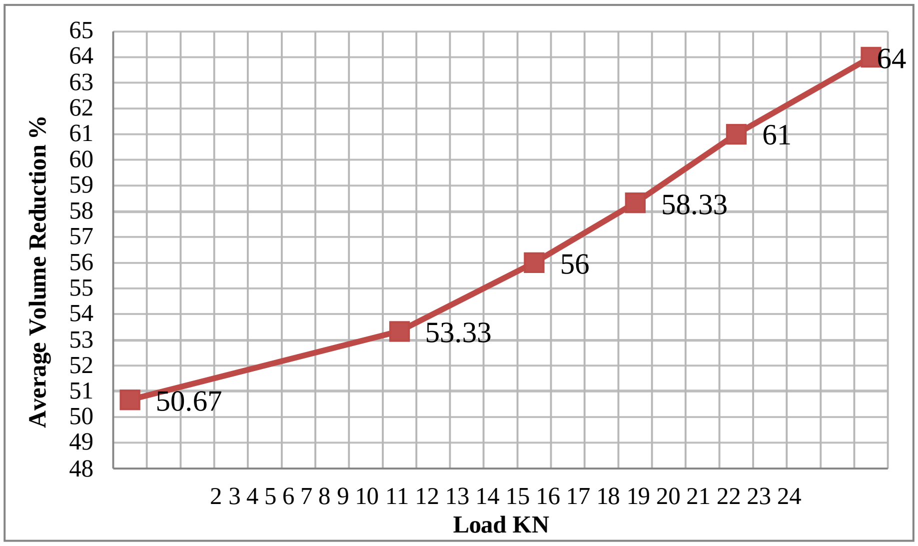


Figure 3 Relationship curve between average volume reduction and applied load

In general, a compression pressure to the order of 2-4 MPa is sufficient to cause the desired compaction of the CSEB (Walker, 1995, Auroville Earth Institute). It is evident from figure 1 that a 9 KN load is required to reduce the volume (height) of the CMOB clay in the mold by 53%, and to reduce the volume to this extent, 2.1 MPa compression pressured was applied on the specimen. Hence to prepare a specimen of 45 mm height, the soil mix was filled in the mold up to 100 mm measured from the bottom and compressed from top till the height was reduced to 45 mm by tightening the jackscrew. Then, the bottom platen was removed horizontally, and the jackscrew was further tightened till the block came out from the bottom of the mold. Before filling the mix into the mold, a thin layer of lubrication oil was applied on the internal walls of the mold, the upper surface of the bottom platen, and the bottom surface of the top lid to prevent friction between mold walls and block while removing the block. The fabricated specimens were stored under the shed, covered with a plastic sheet for 24 hours. After 24 hours, curing was done three times a day for 28 days under a polythene sheet to prevent rapid drying out to assure maximum hydration of the used stabilizer. After 28 days, bricks were kept to dry in the shed for 7 days.

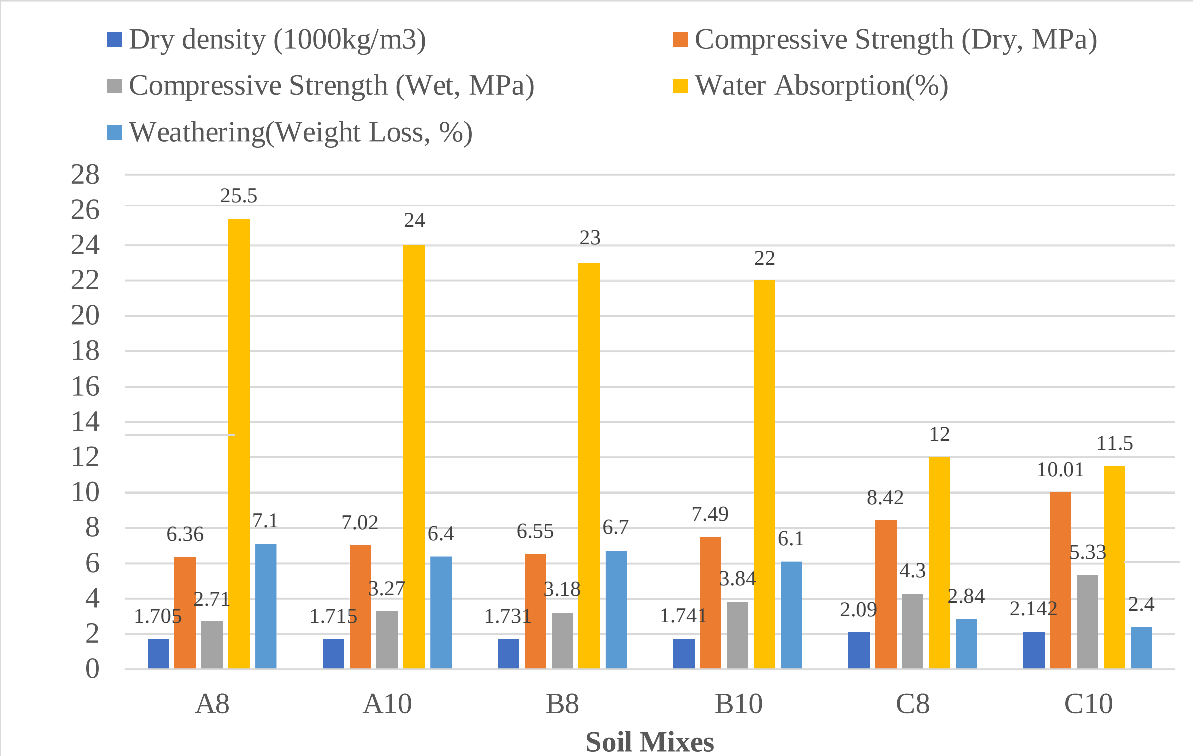
III. RESULTS AND DISCUSSIONS

The results of the various tests such as dry and wet compressive strength, water absorption, and weathering (weight loss) performed on the specimens of CSEBs are presented in table 2. The ratio of the wet to dry compressive strength has also been calculated and presented in the table. The average values of all the tests are also presented in graphical format in figure 4.

Table 2 Summary of tests conducted on bricks made from different soil mixes

Soil Mix	**Stabilizer Content (%)**	**Specimen**	**Dry density (kg/m^3)**	**Compressive Strength**			**Water Absorption (%)**	**Weathering (Weight Loss) (%)**
				Dry (M Pa)	**Wet (M Pa)**	**Wet/Dry Ratio**		
A8	8	1	1726	5.61	2.81	0.50	25.99	7.3
		2	1715	6.55	2.34	0.35	25.51	6.8
		3	1674	6.55	2.81	0.42	25.03	7.2
		4	-	7.02	2.34	0.33	-	-
		5	-	6.08	3.27	0.53	-	-
		Average	**1705**	**6.36**	**2.71**	**0.42**	**25.50**	**7.1**
A10	10	1	1684	7.95	2.81	0.35	24.32	6.50
		2	1741	7.02	3.27	0.46	22.86	6.10

		3	1721	7.49	2.81	0.37	24.83	6.60
		4	-	6.08	3.74	0.61	-	-
		5	-	6.55	3.74	0.57	-	-
		Average	**1715**	**7.02**	**3.27**	**0.46**	**24.00**	**6.40**
B8	8	1	1741	6.55	2.81	0.43	23.67	6.9
		2	1695	7.02	2.81	0.40	22.18	6.4
		3	1757	7.49	3.74	0.50	23.13	6.8
		4	-	5.61	3.27	0.58	-	-
		5	-	6.08	3.27	0.54	-	-
		Average	**1731**	**6.55**	**3.18**	**0.48**	**23.00**	**6.7**
B10	10	1	1767	7.02	4.21	0.56	22.47	6.30
		2	1762	7.95	3.27	0.41	22.27	6.20
		3	1695	7.49	3.74	0.50	21.23	5.80
		4	-	6.55	4.21	0.64	-	-
		5	-	8.42	3.74	0.44	-	-
		Average	**1741**	**7.49**	**3.84**	**0.51**	**22.00**	**6.10**
C8	8	1	2110	7.49	4.21	0.56	12.49	2.84
		2	2064	7.95	3.74	0.47	11.49	2.80
		3	2095	8.42	4.68	0.55	11.99	2.89
		4	-	9.36	4.21	0.45	-	-
		5	-	8.89	4.68	0.53	-	-
		Average	**2090**	**8.42**	**4.30**	**0.51**	**12.00**	**2.84**
C10		1	2178	10.29	5.15	0.50	11.03	2.41
		2	2121	8.89	5.61	0.63	11.71	2.35
		3	2126	10.29	4.68	0.45	11.78	2.45
		4	-	9.82	5.15	0.52	-	-
		5	-	10.76	6.08	0.56	-	-
		Average	2142	10.01	5.33	0.53	11.50	2.40



A. Density

The performance of soil-based building blocks depends largely on their density. Density shows how compact the blocks are. The dry density is largely a function of the constituent material's characteristics, moisture content at pressing, and the degree of compaction effort applied (Walker, 1995). Types of compaction applied, such as dynamic, static, and Vibro, may also affect the density of the blocks (Riza et al., 2010). The density of the compressed earth brick is consistently related to its compressive strength and compressive force applied during production.

The average density of the CSEB specimens fabricated with A8, A10, B8, B10, C8 and C10 mixes is found to be 1705 kg/m3, 1715 kg/m3, 1731 kg/m3, 1741 kg/m3, 2090 kg/m3, 2142 kg/m3 respectively. The density of all the mixes tested are in agreement with the finding of other researchers, who reported the density of compressed stabilized earth blocks within the Range of 1500 to 2000 kg/m3 (Riza et al., 2010, Auroville Earth Institute).

It is found that specimens made with C8 and C10 mixes exhibit much higher density than the specimens prepared with A8 and A10 mixes. Results revealed that there is a 22.6% increase in density of specimen prepared with soil mix C8 with respect to that of soil mix A8 and 24.9% increase in density of specimen prepared with soil mix C10 with respect to that of soil mix A10 due to lowering of the clay content from 22% to 9% in the soil mix. The observed increase in density may be attributed to improvement in the texture of the CMOB clay by lowering the clay content in the soil mix. The CMOB clay used in C8 and C10 mixes are blended with CMOB sand and have better particle size distribution and reorientation of particles resulting in densification and low void ratio than the A8 and A10 type soil mixes. The densities of the specimens prepared with B8 and B10 type soil mixes were also improved Marginally with respect to that of soil mixes A8 and A10, respectively, since its particle size distribution was also improved to a slight extent due to a bit lowering of clay content from 22% to 19%.

The IS code 1725-2013 requires a minimum average dry density value of the CSEB as 1750 kg/m3. All the specimens, except the specimens prepared with mix C8 and C10, fail to attain this density.

B. Compressive strength

Compressive strength is a universally accepted parameter for assessing the quality of bricks. The compressive strength of the CSEB depends on a number of factors, including cement content, types of soil (plasticity index), compaction pressure, and types of compaction (Rizia et al., 2010). Many times, bricks are used under wet conditions and absorb water. CSEBs may lose their strength under saturation conditions due to the development of pore water and liquefaction of un-stabilized clay minerals (Rizia et al., 2010). The tests for dry and wet compressive strengths revealed the following:

1. As the texture of the CMOB clay is improved (clay and silt content decreased and sand content increased) in the soil mixes, both dry and wet compressive strength of the CSEB specimens also improved significantly for both the cement content mix used. Specimen of soil mix A10 with respect to soil mix A8 resulted in a 10.38% and 20.67% increase in dry and wet compressive strength, respectively. Specimen of soil mix B10 with respect to soil mix B8 has resulted in a 14.35% and 20.75% increase in dry and wet compressive strength, respectively. Similarly, the Specimen of soil mix C10 with respect to soil mix C8 has resulted in an 18.9% and 23.95% increase in dry and wet compressive strength, respectively. In all, specimens prepared with 10% cement content (soil mixes A10, B10, C10) exhibit higher compressive strengths both dry and wet than the specimens prepared with 8% cement content (soil mixes A8, B8, C8) for all the clay, silt, sand ratio used.

The results are in good agreement with the findings of Muhwezi & Achanit (2019). They also found that the compressive strengths of compressed stabilized earth blocks using silty clay soil and sand with cement were higher compared to those without sand. Sofi et al., 2016, conducted ***a study on*** CSEBs prepared with a lump of clay having 2% sand, 83% silt, and 15% clay stabilized with a range of cement content and found that both dry and wet compressive strength increased with an increase in cement content up to 10% and beyond that the strength fell with an increase in cement content. A study conducted by Garg et al. (2014) on soil containing 6% clay, 15.4% silt, and 78.6% sand stabilized with cement also revealed that CBSE samples attained the highest compressive strength when stabilized with 9% cement. Walker (1997) also reported a reduction of 40 to 60 % in wet strength of CBSE stabilized with cement. The reduction in wet strength is attributed to pore water pressure and liquefaction of un-stabilized clay due to water absorption.

2. An increase in dry and wet compressive strength was observed due to a decrease in clay content. Specimen of soil mix B8 with respect to soil mix A8 has resulted in a 2.99% and 17.34% increase in dry and wet compressive strength, respectively. Specimen of soil mix C8 with respect to soil mix A8 has resulted in a 32.39% and 58.67% increase in dry and wet compressive strength, respectively. Specimen of soil mix B10 with respect to soil mix A10 has resulted in a 6.70% and 17.43% increase in dry and wet compressive strength, respectively. Specimen of soil mix C10 with respect to soil mix A10 has resulted in a 42.6% and 63% increase in dry and wet compressive strength, respectively. The decrease in clay content resulted in densification, lesser pore water pressure, and more resistance to water absorption causing lesser liquefaction of un-stabilized clay. This has resulted in an increase in wet compressive strength.

The IS code 1725-2013 places a lower limit on average dry compressive strength of CBSE to 3.5 M Pa. The average dry compressive strength of the specimens prepared with all the six types of mixes is found well above the threshold value fixed by the IS code. The code does not demand wet compressive strength to be determined.

C. Water Absorption

Water absorption is a function of clay and cement content and is usually related to the strength and durability of earth bricks (Rizia et al., 2000). Walker & Stace (1997) affirmed that water absorption, as well as the porosity, increases with clay content and decreases with cement content. Water absorption greatly affects the strength and

The durability of the CSEBs. It also affects the bonding of the blocks with mortars during construction. If the block is dry, it sucks out the water of the mortar preventing good adhesion and proper hydration of the cement, and if it is too wet, the mortars tend to float on the surface without gaining proper adhesion (Oti et al., 2009, Walker, 1999).

The average water absorption of specimens prepared with mixes A8, A10, B8, B10, C8, and C10 is found to be 25.5 %, 24.0 %, 23 %, 22%, 12

% and 11.5 % respectively. The IS code 1725 – 2013 restricts the maximum limit of water absorption for CSEB to 18%. The water absorption of the specimens prepared with soil mix A and B exceeded the limit prescribed in the code, whereas the water absorption of the specimen prepared with soil mix C is found well within the limit. The high-water absorption of the specimens prepared with soil mix A and B is attributed to poor gradation (texture) of the soil mixes. Both soil mix A and B has a very low sand content and relatively higher content of clay and silt than soil mix C, and thus will have a higher void ratio than soil mix C.

D. Durability

Durability refers to the ability of the material to maintain its functionality over time. There are several factors that may cause deterioration of building materials like precipitation, moisture, temperature, solar radiation, chemical attack, and intrusion by organisms (Obonyo et al., 2010). The durability of the CSEB is assessed by several test methods like the spray erosion test, the drip test, alternate wetting, and drying test, and the linear expansion on saturation (Nagraj et al., 2016). Among them, alternate wetting and drying and linear expansion on saturation has been adopted by IS code 1725-2013. Alternate wetting and drying were used in this study. This test mimics the abrasive effects of the elements of water and wind erosion on CBSE (Ipinge, 2012).

The average weight loss of specimens prepared with soil mixes A8, A10, B8, B10, C8, and C10 is found to be 7.10%, 6.40%, 6.70 %, 6.10%, 2.84 %

and 2.40% respectively. The tests showed that the weight loss due to abrasion from the wire brush significantly reduced with improvement in the texture of the soil mixes. The average weight loss in the specimens prepared with C-type soil mix was found to be much less than that occurred in specimens prepared with A and B-type soil mixes. The test results also revealed that average weight loss due to abrasion from the wire brush decreases with the increase in cement content for all three types of soil mixes used in the study. The test results concur with the findings of Nagaraj et al. (2016). They investigated the effect of clay content on the durability of CSEB stabilized with cement and found that when clay content was low up to 13%, the loss in mass was low, as the clay content was increased beyond 13%, the loss in mass also started increasing.

The IS code 1725-2013 mentioned the upper limit of weight loss due to wire brush abrasion to 3%. Except specimens prepared with soil mixes C8 and C10, all specimens prepared with other mixes fail to achieve the target limit.

IV. CONCLUSION

The specimens prepared with pure CMOB clay and stabilized with 8% and 10% cement exhibited satisfactory compressive strength, both dry and wet. Although due to its poor texture (high clay and silt content and low sand content), its water absorption and weight loss due to alternate wetting and drying were found very high. CMOB clay can be improved for the production of CSEBs, by blending it with 57% of CMOB sand. The CSEB specimens prepared with this texturally improved CMOB clay with both 8% and 10% cement stabilizer exhibited improvement in strength, water absorption, and durability and met these requirements as specified in IS code:1725 – 2013.

The brick used in testing is reduced to a lab scale. However, experiments can be performed by making bricks of modular size as suggested in IS code. It must be noted that the stabilizers used in brick-making affect the overall economy of the process of brick making. More stabilizers, along with their optimum percentages, can be worked upon.

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