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Evaluation of Coal Mine Overburden Clay for Assessing Its Suitability for Brick Making

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ABSTRACT

Coal mining in India generates huge quantity of overburden waste rock which mainly consists of sandstone. Sandstone found with coal seam is generally argillaceous and hence sand and cementing material can be easily segregated by simple crushing and washing. Sand can be utilized as a fine aggregate in concrete and cementing material which is generally clay minerals has a potential to be used in bricks making. This paper describes a study carried out to investigate the possibility of utilizing clay obtained from overburden waste rock of a large opencast coal mine located in Chhattisgarh state of India. Overburden samples were collected from the mine and mixed with water in the laboratory to separate clay particles from sand particles by sedimentation and decantation method. The obtained clay was sundried and its suitability was assessed for making solid burnt clay bricks and compressed stabilized earth blocks (CSEB).

The chemical composition of the clay was determined by XRF analysis and specific gravity, texture , plasticity index and liner shrinkage were determined by using methods prescribed in relevant IS codes. The optimum moisture content and maximum dry density was determined by using method prescribed in relevant ASTM code. Chemical constituents wise, the clay was found suitable for making both types of bricks. Texture analysis indicates that the clay contains a high amount of silt size particles and due to which its plasticity index was also found less than the desirable value. The texture and plasticity index of the clay can be improved simply by adding some sand size particles which were separated from it during washing of overburden waste rock and clay can be utilized for making both burnt bricks and CSEB.

Keywords: Coal mine overburden, sandstone, sand, clay, burnt bricks, CSEB.

INTRODUCTION

Coal is the prime source of energy in India. It is found in layers or beds buried under the earth called coal seam. There are two main method of coal mining; opencast method and underground method. Opencast method is dominant method and accounts for more than 90% of the total coal produced in India. In opencast mining, first overburden (soil and rock lying above the coal seam) is removed to access the coal seam. Once the coal seam is exposed, it is mined out and overburden is backfilled in the mined-out area. The excess overburden is stacked near pit boundaries as external dumps. External dumps not only demand 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 increased demand of coal and increasing stripping ratio. Earlier, the deposits with stripping ratio of less than 2 were only mined by open cast method, now the open cast mines are being planned for a stripping ratio as high as up to 15 (Das & Choudhary, 2013).

The overburden waste rock consists of mainly sandstone and shale. Among these two, sandstone predominates. The percentage of sandstone may be as high as up to 85% of 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 orferruginous (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. Sand can be used as fine aggregate in concrete and the cementing material obtained as clay has a potential to be used in making bricks. This paper describes a study carried out to investigate the possibility of utilizing clay obtained from overburden waste rock of a large coal mine located in Chhattisgarh state of India.

OVERVIEW OF BRICKS

Bricks are a vital construction material available in a rectangular shape and are used in construction of walls and pavement. In the past, only burnt bricks, which are made from soil, were used but today many types of bricks are available in the market that uses various types of raw material like concrete, lime, fly ash and other industrial and mining waste. A classification of various types of bricks used in India is presented in Figure 1:

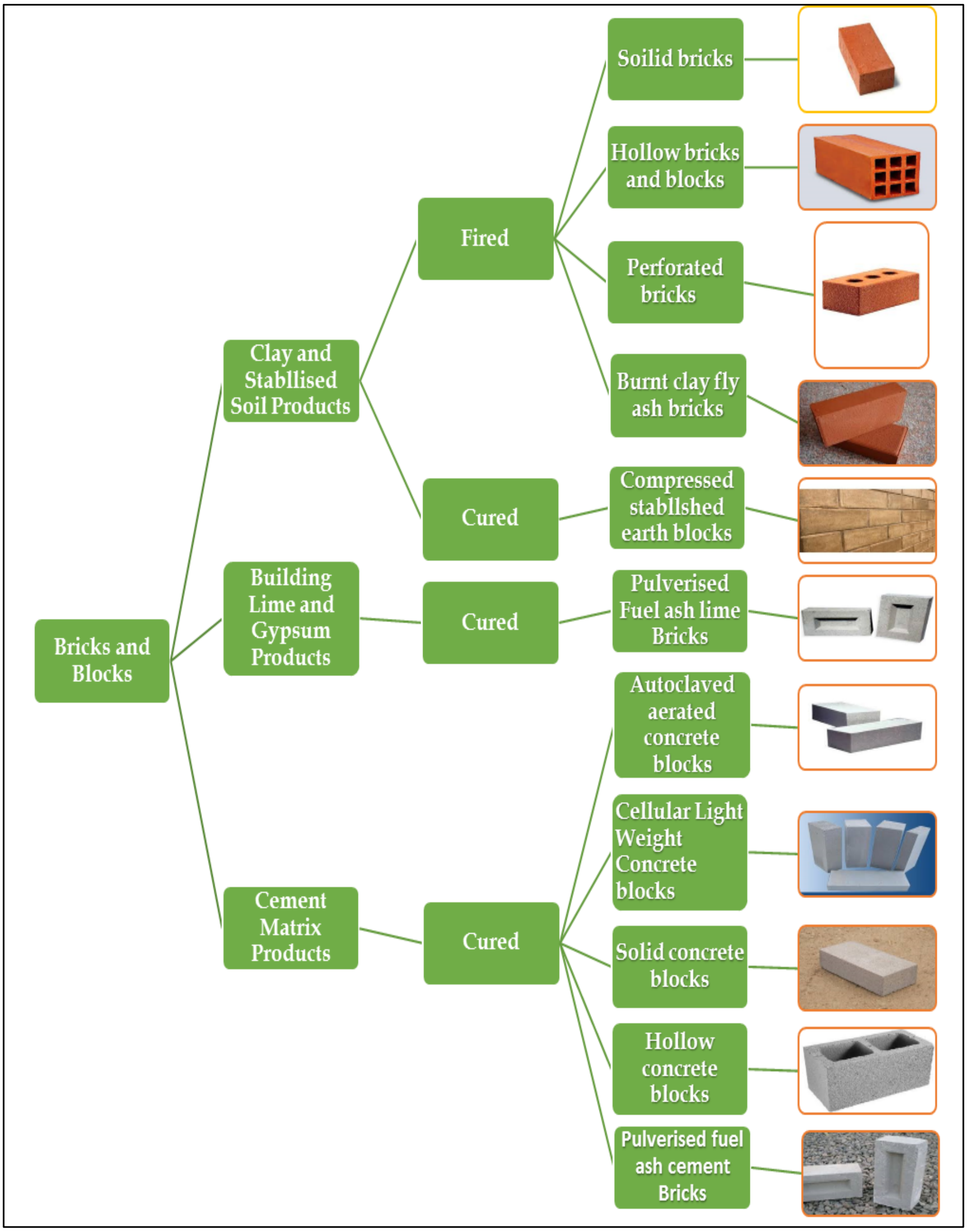

Figure 1: Types of bricks used in India (Shakti Foundation, 2017)

The total production for bricks is estimated to be 274 billion bricks in the year 2014-15 and is estimated to reach a peak of about 1000 billion bricks in the year 2032–37 (Shakti Foundation, 2017). The primary raw material in manufacturing of various types of bricks is summarized in Table 1 below.

Table 1: Raw material used in manufacturing of various type of bricks.

Brick type	**Raw material**	**Brick type**	**Raw material**
Solid burnt bricks	Clay	Autoclaved aerated concrete blocks	Silica-rich material with fly ash/sand, cement, lime, gypsum, aluminum powder/paste,
Hollow bricks	Clay	Cellular light weight concrete blocks	Cement, fly ash, sand, and water, which is further mixed with stable foam,
Perforated bricks	Clay	Solid concrete blocks	Powdered portland cement, water, sand, and grave
Burnt clay fly ash bricks	Clay, fly ash	Hollow concrete blocks	Cement, sand (fine aggregates), and stone chips (coarse aggregates
Compressed stabilized earth blocks	Clay, sand, cement/lime	Pulverized fuel ash cement bricks	Fly ash, lime, gypsum and sand

Among the various types of bricks manufactured in India, the solid burnt clay bricks hold the largest production share (Shakti Foundation, 2017). Clay is the main raw material for manufacturing of bricks. Most of the brick manufacturing units are in unorganized sectors in India, hence no exact statistics is available regarding consumption of clay for manufacturing of bricks. It is estimated that more than750 million tonnes of brick earth/year is consumed in producing bricks (Shakti Foundation 2017).Use of good quality agriculture soil in large quantities for brick making is a grave area of concern. The urbanization and the demand of brick manufacturing have resulted in change of the land used pattern from the good agricultural land turned into agriculturally unproductive lands around several growing cities of the developing world (Kathuria, 2007). It is estimated that with the present production rate of brick in India, about 18000 ha land is degraded every year due to brick earth mining.

On the other hand, India produced about 730 million tons of coal in the 2018-19, more than 90 % of which came from opencast mines. Total 1750 million cubic meter of overburden was removed with an average stripping ratio of 2.56 in the year 2018-19(Coal Controller's Organization, 2019). About 75-80 % of the overburden removed is backfilled in the decoaled area in the mine and remaining 20-25 % is dumped outside the pit. With the present production rate of 730 million tons of coal, about 600-700 ha of land is required every year for construction of external dumps for the waste rock.

MATERIALS AND METHODS

The sandstone samples were collected from Parsa (East)-KantaBasan coalmine of M/s Rajasthan Rajya Vidyut Utpadan Nigam limited, located in the Surguja district of Chhattisgarh state. There are three workable coal seams in the mine with gross reserves of 516.40 million tonnes. To mine this coal 2652.36 million cubic meters of overburden will be required to be remove, resulting in an overall stripping ratio of 5.1. Sandstone is the dominating coal measuring rock in the area and up to 25.0 m depth, the strata is weathered and consist of sludge of fine to medium grained sandstone. At greater depth, medium to coarse grained sandstone is found.

The samples of the overburden were collected from the top sludge horizon only in plastic gunny bags and brought to the laboratory in covered vehicle. Samples were thoroughly mixed and then crushed to break the clumps. Sedimentation and decantation method were used to separate sand particles from clay. About 4 kg of mixed overburden was placed in a plastic bucket of 20 l capacity and 3/4th filled with water and soaked for 15 min. Thereafter, the overburden water mixture in the bucket was vigorously stirred with the help of metal spatula to make a suspension of the clay in water and sediment of sand (see Figure 2a). After some time, the clay-water suspension was slowly poured in a 200 l capacity plastic drum cautiously without disturbing sand particles deposited at the bottom in the bucket(see Figure 2b).The bucket was again filled with water and stirred and the process was repeated till clear water is observed in the bucket.

Figure 2: a. Stirring of overburden water mixture.
b. Poring of clay water mixture in the drum.

Figure 2: a. Stirring of overburden water mixture. **b.** Poring of clay water mixture in the drum. **c.** Settlement of clay at the bottom of the drum. **d.** Sundrying of clay slurry

The deposited sand (CMOB sand) in the bucket was emptied on flat surface covered with plastic sheet and kept for sundry. The suspended clay in the drum was allowed to settle overnight and clear water was siphoned out from the drum(Figure 2 c).The settled clay in the drum in the form of slurry was also poured on plastic sheet spread on a hard floor for sun drying as shown in Figure 2 d. The recovery percentage of clay was about 18%.Figure3 depict the overburden sludge, CMOB sand and CMOB clay.

Figure 3: Overburden, CMOB clay and CMOB sand

The suitability of the CMOB clay was assessed for making solid burnt clay bricks and compressed stabilized earth blocks (CSEB). Production of burnt clay bricks involves four operations: preparation of clay, molding of clay into bricks, drying of bricks, and burning. Bricks are burned at high temperature to gain the strength, and durability. At high temperature silica reacts with alumina and chemical bonding takes place which gives the required strength to the bricks. Thus, the composition of the clay used in making bricks plays an important role in deciding the strength of the brick. The main operations involve in production of CSEB are preparation of clay, mixing of a suitable stabilizer with clay, compression to mold the mixture into brick shape and size, curing of the bricks and drying. The strength of the CSEB depends mainly upon the grain size distribution of the clay, degree of compaction and type and quantity of the stabilizer used. There is no standard that prescribe the quality of the clay to be used in making burnt bricks and CSEB. Based on the manufacturing process and literature, the following tests have been conducted on the CMOB clay to assess its suitability for making burnt bricks and CSEB.

	Name of the test	**Method/ BIS Code**
1	Composition	XRF
2	Specific gravity	IS: 2720 (part III/sec-1) – 1980
3	Texture	IS: 2720 (Part IV)- 1985
4	Plasticity Index	IS: 2720 (part V) – 1985
5	Maximum dry density and Optimum moisture content	ASTM D698-12, 2012
6	Linear shrinkage	IS: 2720 (part-20)- 1966

RESULTS AND DISCUSSIONS

1. Composition of clay:

The results of the XRF and limits of various constituents recommended by researchers (Gopi S 2009, National Institute for Interdisciplinary Science and Technology, 2011) for good quality soil for burnt bricks is presented in Table 2.Constituents of the clay for making CSEB are stabilized using cement and hence recommended limit of constituents of clay is not found in available literature for CSEB.

Table 2: Constituents of the CMOB clay and its recommended limits for burnt clay bricks and CSEB.

Constituents	Percentage in the CMOB clay	Recommended limit for burnt clay bricks	Recommended limit for CSEB
Alumina	28.72 %	20-30	-
Silica	50.46%	50-60	-
Iron Oxide	6.29%	5-7	-
Lime	Trace	2-5	-
Magnesia	Trace	<1	-
Potassium Oxide K_2O	4.53%		-
Sodium Oxide Na_2O	0.34%		-
Sulphur Trioxide SO_3	Trace		-
Loss on Ignition (LOI)	8.75%	10 %	-

Burnt clay bricks obtain strength only after firing at a suitable temperature. The chief constituents of the brick clay are silica, alumina, iron oxide, lime and magnesia. The silica content in CMOB clay is found to be 50 %, which is within the range generally consider sufficient for making burnt clay bricks. Silica is the primary constituent of any soil. It is present in the soil in both free and combined form with alumina. Free silica is found mechanically mixed with clay. It gives strength and rigidity to the green bricks. Silica present in combined form reacts with alumina at vitrification temperatures to form mullite, which give the required strength to the bricks (VSBK Programme, 2008).Alumina is another important constituent required for making burnt brick. Its recommended range is 20-30 % in the clay. The percentage of alumina in CMOB clay is also found within the recommended range. Alumina render the clay plastic in wet conditions and thus helps in molding process. It also reduces shrinkage during drying and gives strength to the bricks. Burnt clay bricks are red in color due to presence of iron oxide in the soil (VSBK Programme, 2008). It also acts as a flux and lowers down the softening temperature of silica. Presence of excessive iron oxide in clay may cause too softening of the bricks during firing, as a result of which, bricks may deform in shape. The recommended range of iron oxide in the brick clay is 5 to 7 %, In CMOB clay the percentage of iron oxide was found well within the recommended range. The recommended range of lime in the brick clay is < 5 %. It helps in burning and hardening of the bricks quicker. It should be present in powdery form. If it is present in excess quantity and in nodules form, it is deleterious resulting in lime bursting. The lime in CMOB clay was found in traces, indicating the need of higher firing temperature of the bricks made by it. The effect of presence of magnesia in the brick clay is similar to that of lime. Magnesia is also reported in traces in CMOB clay.

2. Specific gravity:

Specific gravity of the soil decides the mass of the brick made from it. It depends on the mineral composition, particle size distribution of components, texture, resulting void ratio and moisture contents (Adyel et al 2012). The specific gravity of typical soil usually lies from 2.65 to 2.85. Iron rich soils have a larger value of specific gravity than silicas (Bowles 2012). Since the bricks made of clay having higher specific gravity will weigh more, clay having less specific gravity are preferred in brick making. There is no standard that prescribe the specific gravity of clay for making burnt brick and CSEB. The specific gravity of the CMOB clay is found to be 2.68.

3. Texture:

Texture indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. It is a vital property of the soil as the molding capability of the soil depends on its texture. Water and air holding capacity of the soil and the rate, at which water can enter and move through soil, also depends on its texture (FAO, 2020).Sand helps in molding of soil into bricks as it does not stick to hand or mold. Clay impart plasticity to the soil under moist conditions (VSBK Programme, 2008).Plasticity is due to the thin film of absorbed water which adheres strongly to the clay layers thus linking the particles together (Grimshaw,1971). A high proportion of clay results in cracking of bricks due to excessive shrinkage. Soil with low proportion of clay, has low cohesive strength and high strength bricks cannot be made from such type of soil. Silt act as filler between sand and clay and gives a homogenous structure. It also controls plasticity and prevents shrinkage during drying. The texture of the CMOB clay and recommended limits for burnt clay bricks (VSBK programme, 2008) and CSEB (Auroville Earth Institute)is presented in Table 3.

Table 3: Texture of the CMOB clay and its recommended limits for burnt clay bricks and CSEB.

	CMOB clay	Recommended limits for burnt clay bricks	Recommended limits for CSEB
Pebbles %	--	--	15
Sand size particle (%)	18.00	20-45	50
Silt size particle (%)	60.00	25-45	15
Clay size particle (%)	22.00	20-35	20

The CMOB clay analyzed contains a high percentage of silt and low percentage of sand. This is because the sand size particles have already been separated from the sandstone during washing of sandstone by sedimentation and decantation process and only the fine particles that remain suspended in the water were considered for analysis.

4. Plasticity Index

The plasticity index (PI) is a measure of the plasticity of a soil. It gives the size of the range of water contents where the soil exhibits plastic properties. Soils with a low plasticity index are difficult to handle for brick-molding. A brick made of a soil with low plasticity index deform when taken out from the mold, if the soil contains a small excess of water; if it lacks sufficient water, the soil becomes too stiff to mold (ILO & IRODO, 1984).Soils with high plastic limit requires more water to mold it into bricks and thus longer drying period of bricks is required in such types of soils (ILO & IRODO, 1984). The plasticity of soil depends on many factors such as the chemical constitution of clay, the physical nature, presence of impurities, clay content, and presence of organic content and free silica content. The determined value of plasticity index of CMOB clay, and its recommended value for burnt clay brick (National Institute for Interdisciplinary Science and Technology, 2011) and CSEB (Auroville Earth Institute)are presented in Table 4.

Table 4: Plasticity index of the CMOB clay and its recommended limits for burnt clay bricks and CSEB.

	CMOB clay	**Suggested limits for burnt clay bricks**	**Suggested limits for CSEB**
Plastic limit	17.15	-	-
Liquid limit	30.00	-	-
Plasticity Index	12.85	>23	Low but not less than 20

5. Maximum Dry Density and Optimum Moisture Content:

CSEBs are prepared by compressing a damp mixture of soil and stabilizer. Apart from the quality of clay used, type and quantity of stabilizer used, the quality of CSEB also depends upon the degree of compaction of the block. At optimum moisture content, soil can be compacted to maximum degree with least compaction energy (Rizia et al., 2010). Thus, maximum dry density and optimum moisture content of a soil is an important property for selection of a soil for using it for making CSEB. The MDD and OMC of the CMOB clay as determined by Standard Protector Tests is found to be 17.05kN/m^3 and 18.50 % respectively.

6. Linear shrinkage:

Drying behavior of soil is an important criterion for evaluating a soil for making burnt clay bricks. A brick made of a soil with high degree of shrinkage is likely to crack during the drying process. Drying shrinkage of soil depends upon the clay content of a soil and type of the soil. A soil with high clay proportion may crack during drying due to high shrinkage. Mitchell (1976) mention that the greater the plasticity, the greater the shrinkage on drying. A freshly molded green brick shrinks until the added water is evaporated and the particles of clay body have formed as a stable framework (VSBK Programme, 2008).Linear shrinkage is also used to determine the mold size to be used for making burnt bricks.

Drying shrinkage of CSEB mainly depends on plasticity index and cement content in the mix. For soil with plasticity index below 20%, drying shrinkage increase with the increase in clay content steadily while for soil with plasticity index beyond 25% drying shrinkage increases rapidly as the clay content is increased (Riza et al. 2010). Linear shrinkage test is used to determine the amount of cement or lime to use for soil stabilization.

The determined value of linear shrinkage of CMOB clay, and its recommended value for burnt clay brick (National Institute for Interdisciplinary Science and Technology, 2011) in Table 5.

Table 5: Linear shrinkage of the CMOB clay and its recommended limits for burnt clay bricks and CSEB.

	CMOB Clay	**Recommended limits for burnt clay bricks**	**Recommended limits for CSEB**
Linear Shrinkage	4.8 %	<10 %	---

The linear shrinkage of CMOB clay is found to be much below the recommended value for burnt clay bricks. Linear shrinkage is of clay is not much important for making CSEB blocks, as CSEB is molded by compression and cement is used as stabilizer which reduces the shrinkage. For CSEB no recommended value is found in available literature.

CONCLUSIONS

Bricks are generally made by native clay. The values recommended by researchers for various properties for brick clay are ideal values which rarely meet in the clay used in brick making. The chemical constituents of the clay for making burnt bricks are vital. Chemical constituent wise, the CMOB clay is found suitable for making both types of bricks but texture wise, the clay is found unsuitable for making both burnt bricks and CSEBs. The CMOB clay contains high proportion of silt and very less amount of sand, and because of this its plasticity index is also very low. If burnt bricks are made of using this clay, it will be difficult to mold them into bricks as the bricks may deform when taken out from the mold. CSEBs will pose less difficulty in molding as these are molded by high compression and use cement as stabilizer. Also, the bricks prepared may absorb more moisture and may have a low wet strength. The texture and plasticity index of the CMOB can be improved simply by adding some sand size particles which were separated from it during washing of overburden waste rock and clay can be utilized for making both burnt bricks and CSEB.

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