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Utilisation of Mine Waste in the Construction Industry – A Critical Review

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Abstract: The exploitation of mineral resources would promote the development of economy and society, but it will also generate massive waste/tailings that may pollute the environment significantly (in the form of spreading of waste in and around the mines, siltation of soil/slimes in nearby water bodies, air pollution etc.) Therefore, developing comprehensive utilization of waste fines/tailings in large scale is the need of the day in order to improve the surroundings and for sustainable development of resources. Manufacturing of non-fired bricks is one of the options for utilization of waste generated in mines along with reduction of CO_2 emission. If the waste material is improperly dumped in mine site, the flow of material during rainy season may reduce the fertility of nearby agricultural land. Hence, waste utilization plays a vital role in natural resource conservation. Further, building blocks/bricks from mine waste is 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. Hence, it is very much necessary to find alternative for making use of iron ore waste material (fines)/tailings as an aggregate in construction materials like bricks or paving blocks. This paper provides a critical review of the utilization of mine waste for brick making in the construction industry.

Keywords: *Exploitation, Bricks, Iron ore waste, Tailings, Aggregate, Overburden, Sustainable development*

Introduction

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 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. Iron-ore waste generated is likely to increase in future due to higher demand for iron ore as a number of steel plants have been planned in many parts of the country. In India the production of iron ore was 218.64 million tons (IBM, 2013) and the total production of iron ore in India is expected to exceed 400 million tons within the next decade. Waste rocks are the unused material produced during the extraction process, which is dumped in appropriately in the mine lease boundary. Mainly waste rocks overlying on the ore body needs to be removed in large quantities for ore extraction, which forms the major mine waste also called as overburden. The overburden ratio for surface mining of metal ores generally ranges from 1:2 to 1:6 depending on the local conditions. For every ton of metal extracted from the ore, roughly 212 tons of overburden material is removed. Generally, open cast mines and quarries generate much more mining wastes compared to underground mines (Mohanty, 2010). The exploitation of mineral resources would promote the development of economy and society, but it will also generate massive waste/tailings that may pollute the environment heavily and bring other issues such as occupying land and wastage of resources. Therefore, developing comprehensive utilization of waste fines/tailings in large scale is one of the prospective way to promote production efficiency, and also it is important in saving resources, improving surroundings and for sustainable development (Zang et al. 2006). It is therefore imperative that state-of-the-art iron-ore mining and processing technologies to be adopted to address and implement effective utilization of tailings. 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. The manufacture of building bricks without burning of solid fuel is one of the options for utilization of mining and industrial wastes and reduction of CO_2 emission by adopting innovative and sustainable processes such as mineral polymerization and mineral cementation (Chakravarthi et al. 2007; Muduli et al. 2010).

2. Literature review:

Researches have been carried throughout the world in the area of manufacturing of bricks using various materials, both natural resources and waste materials. Further, the bricks were also made by various processes and technologies. Following section highlights the types of bricks based on the material used and the process adopted.

2.1 Types of bricks based on Indian standards:

a) Common bricks:

Common bricks are multi-purpose bricks manufactured economically without special reference to its appearance. It is suitable for general building work and widely used for foundations, as a backing for rendering, plaster or color wash and also popular for inner leaf of cavity walling (Lunch, 1993).

b) Facing bricks:

Facing bricks are good in appearance and are used for filling in front of building walls for which a pleasing appearance is desired (Lunch, 1993).

c) Engineering bricks:

Engineering bricks are strong, impermeable, smooth, table molded, hard and conform to defined limits of compressive strength and water absorption. These are used for all load bearing structures, construction of bridge, aqueducts, engine pits, power houses, damp proof courses etc. Their name derives from their use in civil and allied engineering (Lunch, 1993; Duggal, 2008).

d) Special bricks:

Special bricks are classified based on their shape, specification and special purpose for which they are made. These bricks are different from the commonly used building bricks.

e) Special shaped bricks:

Special shaped bricks are used to suit the different situation. The dimensions of these bricks vary. These bricks are used as closers, copings, bullnose bricks, corner bricks, plinth bricks, culvert bricks, chimney bricks and well type bricks etc.

f) Burnt clay facing bricks:

Burnt clay facing bricks are used for the exposed face of masonry, without further surface protection. As per Bureau of Indian Standards (BIS) (IS: 2691:1988) these types of bricks are mainly divided into two major classes such as i.e., Class I and Class II. The compressive strength of Class I should not be less than 100 kg/cm^2 whereas of Class II, it should not be less than 75 kg/cm^2. The water absorption requirement for 24 hours immersion should not exceed 15 %.

g) Heavy duty bricks:

Heavy duty bricks have high compressive strength, low water absorption and should be free from cracks. The compressive strength of these bricks varies from 40 MPa to 45 MPa and total water absorption is less than 10 %. These types of bricks are mostly used for heavy engineering works, like bridge structures, industrial foundations etc. (IS-2180:1988).

h) Perforated building bricks:

Perforated building bricks have better thermal insulation compared to common type of bricks. Sizes of these bricks are varies from 19 cm × 9 cm × 9 cm to 29 cm × 9 cm × 9 cm (IS:2222-1991). According to the BIS (IS: 3495-1976) a minimum compressive strength of the brick should be 7 MPa with maximum average water absorption of 15 % by mass.

i) Burnt clay hollow blocks:

Burnt clay hollow blocks are light in weight and being hollow, which imparts thermal insulation to the buildings. It is used in limited scale for walls and partition in our country.

j) Sand lime bricks or calcium silicate bricks:

Sand, lime bricks consist of siliceous sands and limes combined by the action of saturated steam under pressure. Generally, these bricks are used for masonry construction. According to the BIS (IS: 4139-1976) the size of the sand lime brick is 19 cm × 9 cm × 9 cm and 19 cm × 9 cm × 4 cm. These bricks are classified in to four classes according to their average compressive strength, which should not be less than 7.5 MPa, 10 MPa, 15 MPa and 20 MPa, respectively.

k) Sewer bricks:

Sewer bricks manufactured from clay, fire clay or shale or combination of these materials. As per BIS (IS: 4885-1988) the size of these bricks are 19 cm × 9 cm × 9 cm and 19 cm × 9 cm × 4 cm. The average compressive strength of sewer bricks should not be less than 175 Kg/cm^2. The average value of water absorption for five bricks after 20 hours in cold water immersion should not exceed 10 % of average dry weight of bricks.

l) Acid resistant bricks:

Acid resistant bricks are made of clay or shale of suitable composition with low lime, low iron content, feldspar, sand and vitrified at high temperature in ceramic kiln. It is designed for use in chemical and allied industries. As per Bureau of Indian Standards (IS: 4860-1968) the dimension of these bricks is 23 cm × 11.4 cm × 6.4 cm. These types of bricks are manufactured in two classes. The Class I bricks having minimum average compressive strength of 68.65 MPa and maximum water absorption of 2 %. These classes of bricks are recommended for corrosive environment like storage tank, pickling tank etc. The

Class II bricks having minimum average compressive strength of 49.03 MPa and maximum water absorption of 4 %. These bricks are used for floors and working areas which are subjected to occasional spillage of acid. It is also used for skirting and lining of silos.

m) Refractory bricks:

Refractory bricks are manufactured using refractory clays which withstand very high temperature. The primary requirements of this bricks are its materials properties (physical and chemical) i.e. it should be stable at high temperature. These bricks are also defined as non-metallic material suitable for the construction of furnaces which operated at high temperature (Kulkarni, 1999).

Table 1 gives the detailed clarification of heavy duty and commercial burnt clay bricks based on compressive strength (IS: 2180-1988, IS: 1077-1992)

2.2 Classification of the bricks based on manufacturing process and type of ingredients:

a) Steam curing-free bricks:

An experimental study conducted on iron ore tailings shows that a burnt and steam curing-free bricks (iron tailing, fly ash, sand, CaO, gypsum and cement) has compressive strength of 28.30 MPa and flexural strength of 5.63 MPa (Gan et al., 2011).

b) Non-fired bricks:

Youngliang et al. (2011) utilized hematite tailings in manufacturing of non-fired bricks by pressing and curing process in the presence of cementing material and coarse aggregates. The factors influencing the mechanical strength of the bricks, like forming water content, forming pressure, content of tailings in raw material and curing condition were investigated. Results of the study indicates that non-fired brick with 78 % hematite tailings can be prepared in the optimal condition at 15 % water content and 20 MPa pressure. The suitable curing condition is in room temperature for 28 days. It was also found that comprehensive strength of products can be up to 15.9 MPa with other physical properties and the durability were well confirmed to Chinese non-fired gangue brick standard. Muduli et al. (2010) prepared cold setting building bricks from mining and industrial wastes. It was observed that, in atmospheric temperature ranging 20° - 35° C and hot air temperature below 100°C, a considerable binding strength is developed. The results of the investigation indicates that the bricks produced by polymerization reaction using 95 % fly ash, 50 % beneficiated iron ore tailings and red mud attain 80 to 14.71 MPa crushing strength under atmospheric curing condition. This process is flexible and cost effective for using the waste materials from any source having thermal and non-thermal effect in preparation of cold setting building bricks.

Table 1: *Classification of bricks based on compressive strength*

	Average compressive strength not less than (MPa)	Class designation
Heavy duty bricks	45.00	5.00
	40.00	40.00
Common burnt clay building bricks	35.00	35.00
	30.00	30.00
	25.00	25.00
	20.00	20.00
	17.50	17.50
	15.00	15.00
	12.50	12.50
	10.00	10.00
	7.50	7.50
	5.00	5.00
	3.50	3.50

c) Fired bricks:

The experiments performed by Yongliang et al. (2011) shows that the eco-friendly bricks prepared from hematite tailings and the additives of clay and fly ash improves the brick quality. The bricks were made through the process of mixing, forming, drying and firing. The results indicated that the mechanical strength and water absorption of the fired brick specimens were in the range 20.03 - 22.92 MPa and 16.54 - 17.93 %, respectively. The other physical properties and durability were as per Chinese Fired Common Brick Standard.

d) Autoclaved bricks:

An attempt was made by Zhao et al. (2012) for utilizing hematite tailings for preparing high strength autoclaved bricks to use in the construction industry. To achieve high strength of bricks, the hematite tailings were added to the mixture of lime and sand which are in 70:15 ratios. The autoclave pressure 1.2 MPa with 6 hour timing, gives the compressive strength 21.2 MPa and flexural strength 4.21 MPa. The requirement in autoclaved lime-sand brick standard for MU-20 autoclaved bricks satisfied with the mechanical and freezing-thawing resistance properties.

e) Clay bricks:

A study carried out by Nwofor (2012) on mechanical properties of clay brick masonry in which mechanical properties of constituent materials of masonry influences its structural behavior. Uniaxial compressive test was carried out on unreinforced masonry and its constituents to obtain their basic mechanical properties. The compressive stress-strain relationships at different confining stress levels were obtained. The nonlinear stress-strain curves were also obtained for masonry with salient points identified on the stress-strain curves, with stress level of 0.40 F_m corresponding to the limit of the nonlinear region. Simple analytical model was proposed for prediction of modulus of elasticity of masonry, to aid the numerical analysis of masonry structures. The test results obtained on brick units and masonry was enough to predict the modulus of elasticity of masonry.

Bricks and roof tiles made out of clay is widely used in recent buildings and structures. Degradation of these materials is caused due to exposure into salt spray bath. This leads to their functional, aesthetic, economical and safety problem. Various physical and mechanical alterations caused by salt spray test were analyzed and observed that large pores do not have significant effect on degradation of materials. But if large amount of smaller pores are present then it may cause severe damage in the ceramics and hence, it leads to more degradation. It was concluded by quantifying mechanical properties, the existence of degradation at different scales between samples, the strength showed a decrease of more than 20 % and water absorption increased more than 40 %, which is an effect of coastal environment (Fonseca et al., 2013).

Brencich et al. (2005) performed experiments to study the compressive strength of solid clay brick masonry under eccentric loading. Experimental data on eccentrically loaded solid clay bricks and lime-mortar masonry was presented. The evolution of the crack pattern was in agreement with the rots who conjectured that the collapse mechanism is activated by some local edge effect. The experimental results showed that the assessment of arch-type structure relying on a purely No-Tensile-Resistant (NTR) model turned out to be significantly conservative. The results also showed that the limit-analysis approach somehow over estimates the actual compressive strength of masonry.

Stress-strain relationship is a significant property for construction materials. These relationships were available in literature for concrete and steel but not for masonry. Four different bricks and three mortars were used and uniaxial compressive testing of 84 masonry prisms was conducted. The study proposed analytical expression to estimate modulus of elasticity of masonry. It was found that modulus of elasticity vary between 250 and 1100 times the prism strength of masonry. The compressive strength of masonry was found to increase with that of the bricks and mortar and it was more striking in case of masonry made of weaker mortar and also adding lime to mortar was recommended as it increases the compressive deformation by 50 % and reduction in compressive strength was only about 13 % when lime mortar was used (Hemanth et al. 2007).

The bonding behavior of historical clay bricks strengthened with steel reinforced polymers. In the strengthening interventions of past and historical masonry constructions, the non-standardized manufacture process, the ageing and the damage of masonry units, could significantly affect the properties of the surfaces where strengthening materials are applied. Different bond tests were conducted on new manufactured and old bricks. Based on the different characteristics of the bricks like compressive strength and the properties of the exterior surfaces where the strengthening is applied, different bond behavior that emerged from the tests was examined. The results of the tests showed that regular surfaces with uniform porosities distribution, which were commonly found in new bricks and old bricks, lead to a good level of adherence between strengthening system and the support and were characterized by a debonding mechanism which involved the detachment of the support material. Also bricks characterized by macro irregularities did not guarantee good adherence, bricks with weak surfaces but high porosity guaranteed good adherence (Ernesto et al. 2011).

Cigarette butts are toxic wastes, due to poor biodegradability of cellulose acetate filters, it gets accumulated in the environment. Study was made to incorporate cigarette butts in fired clay bricks. Four different clay-cigarette butts mixed with 0, 2.5, 5.0, 10.0 % by weight cigarette butts, corresponding to about 0, 10, 20 and 30 % by volume were used for making fired clay bricks. Various physico-mechanical properties were studied and the results showed that density of fired bricks was reduced by up to 30 %, depending on the percentage of cigarette butts incorporated into the raw materials. Similarly, the compressive strength of the bricks reduced from 25.65 MPa to 12.57, 5.22 and 3.00 Mpa for 2.5, 5.0, 10 % cigarette butts content, respectively. Water absorption values increased from 5 to 18 % and initial rate of absorption was also found to increase. The results showed that cigarette butts can be used to make good quality bricks (Aeslina et al. 2010).

A literature review was carried out on comparing clay bricks nomograms with fly-ash bricks. Bricks made out of fly- ash are well known in recent days. Fly-ash is being accumulated in environment in large quantities. Comparison was done between clay bricks and fly-ash bricks nomograms which are given in national building code SP: 10 -1975. Different nomograms were used for different buildings to calculate external and internal wall thickness. Prism test was used to calculate basic compressive stress and the results proved that fly-ash bricks are safer, economical and higher strength compared to conventional bricks (Dhaval et al. 2011).

f) Interlocking bricks:

Carrasco et al. (2013) performed technical evaluation of walls constructed with interlocking bricks of iron ore by-products and cement. Three walls with dimensions of 150 cm width, 240 cm height and 15 cm thickness were built and tested. The first fissures arose with a stress of 0.56 MPa, corresponding to only 3.8 % of the rupture stress of the brick alone. Horizontal displacement was negligible in all the walls and buckling was not observed. Results showed high compressive strength of 14.57 MPa for bricks, 9.82 MPa of the prisms and 25.2 MPa of the mortar and walls showed good mechanical strength of 2.05 MPa, which represents 14 % of the brick strength. Deformations were high, with axial deformation modulus of 420 MPa, which indicates a flexible behavior of the wall. It is also observed that stress is only 13.6 % of the compressive strength (2.05 MPa) of the wall and 1.9 % of the brick, which indicates that there is a very large reserve in terms of strength.

g) Stabilized mud blocks:

An attempt was made by Ullas et al. (2010) to replace natural river sand with iron ore tailings in manufacture of stabilized mud blocks (SMB). Bricks were prepared with sand and iron ore tailings with ratio of 1:0, 0.75:0.25, 0.50:0.50 and 0:1, with 0 % cement and 50 % soil. The size of the mud bricks was 230 mm × 110 mm × 70 mm, which was cured under wet burlap for 28 days. The results of the study revealed that the compressive strength of wet mud block is 7 MPa. Further, the water absorption of the block was increasing with increase in iron ore tailings (IOT) percentage, but this increase is within the limit. A study carried out by Dong-Yan Liu and Chuan-Sheng Wu (2012) on possibilities of utilization of red mud as a building material and filler material, it is the most effective way to reduce the stockpiling of red mud. Red mud used for environmental remediation materials is a new hotspot and worth promoting for its simple processing and low cost. The author concludes that, red mud can be used in brick industry and cement industries too.

h) Paving blocks / building blocks:

It is proved that the iron ore tailings can be effectively utilised in manufacturing of paving blocks. Aruna (2012) in his study used cement, jelly dust, baby jelly and iron ore tailings for making blocks. Three different types of mix were used; five samples were prepared from each having different proportions and cured for 7 days and 28 days. It was concluded that the modified mix with tailings proportion 1:0.75:0.75:3 has the highest compressive strength of 36.5 MPa for 28 days curing. The least compressive strength obtained was 6.8 MPa for the modified mix with sand for same time period of curing. However, the highest water absorption was 7.02 % and lowest was 2.6 % for cement: jelly dust: baby jelly with ratios 1:5:10 and 1:1.5:3. An attempt was made by Prahallada et al. (2014) to study the suitability of iron ore tailings in the preparation of building blocks by stabilizing it through cement. Dry compressive strength, wet compressive strength, water absorption and erosion resistance were found out on the prepared specimens. It was found that the stabilized blocks of iron-ore tailings shows increase in the erosion resistance and decrease in absorption with the increase in the curing period and stabilizer percentage. It was also found that the ratio of wet to dry compressive strength lies between 0.50 and 0.73.

An experimental study carried out by Ravikumar et al. (2012) on iron-ore tailing based interlocking paver blocks, which gives the properties of interlocking concrete block pavers (ICBPs) mixed with iron ore tailings as a partial replacement for cement. The strength characteristics and water absorption of iron ore tailings based concrete paver blocks by considering actual area and plan area were also carried out. Through the experimental investigation it was observed that the strength obtained is more in case of actual area (21.46 MPa with 7 days curing and 26.34 MPa with 28 days curing) compared to plan area, indicating the more conservative (20.35 MPa with 7 days curing and 24.98 MPa with 28 days curing. It was concluded that, use of iron ore tailing from 5 % to 15 % has shown increase in the compressive strength of the concrete compared to normal concrete. Whereas, addition of iron ore tailings from 15 % to 25 % has resulted in lower compressive strength compared to that of conventional concrete.

i) Ceramic products:

Earlier study reported that, iron and steel plant waste as well as iron ore tailings can be used in manufacturing of ceramic products such as ceramic floor, wall tiles etc. The major raw materials used in the study were iron ore slime, fly ash and blast furnace slag. Some special additives along with alumina-silicate were used for this study. It was found that these tiles have high strength and hardness compared to conventional tiles and also it conforms to most of the European Standards. The investigations also revealed other benefits like energy economy and lower production costs, and it was proved that such tiles have high strength and hardness compared to conventional tiles (Das et al., 1996 and 2000).

An innovative methodology for utilization of wastes from metallurgical and allied industries highlights the usage of fly ash, blast furnace slag and iron ore tailings in preparation of floor and wall tiles. Further, fly ash was also used as value added product in preparation of synthetic granite. It was observed that partial addition of iron ore tailings, fly ash and blast furnace slag in suitable combination will improve scratch hardness (> 6 on Mohr's scale) and flexural strength (> 25 MPa) of ceramic tiles. Moreover the properties of those prepared tiles satisfied the European Specification. The synthetic granite tiles using fly ash were reported very low porosity (< 0.5 %), high bending strength (38 MPa) and dense microstructure (Sanjay et al., 2006).

Iron ore tailings and waste rock were used by Jian et al. (2011) to manufacture the sintered wall material. The study showed that the tailings and waste rock can be used as wall materials. It was also concluded that, due to higher iron content in iron ore tailings and waste rock, the products experimented the reduction in the sintering temperature with decreased energy consumption.

An experimental study carried out on utilization of Mn - Fe solid wastes which are generated from electrolytic MnO_2 production, in the manufacture of ceramic building products. As per Sikalidis et al. (2007), particular waste treated with calcium hydroxide can be used for the manufacture of heavy clay building products prepared either by extrusion or by powder pressing. These wastes can also be added to the ceramic at the ratio from 5 % to 7.5 % to improve the basic properties of the products such as water absorption and bending strength. A study carried out by Yongliang et al. (2013), hematite tailings was also used in preparation and characterization of red porcelain tiles together with kaolin and quartz sand. Considering the firing temperature, amount of additional tailings, phase compositions and microstructure, the final fired samples were studied. The samples displayed a good sintering property in line with standard specifications in ceramic tiles. Firing temperature and hematite tailings had significantly influenced sintering behavior of porcelain tiles. Increasing sintering temperature improves the densification and mechanical properties of samples, but temperature above sintering range causes drastic fall of the physical and mechanical properties due to over firing.

Tailings addition promoted the samples densification at lower temperatures, however, too high tailings content narrowed sintering temperature interval. The suitable formulation was suggested as addition of hematite tailings (55 - 65 % by weight), kaolin (25 % by weight) and quartz sand (10 – 20 % by weight) and fired at 1200˚ C for 30 minutes. The XRD and SEM results showed that good physical and mechanical properties are associated with mineral phase compositions and dense microstructure.

j) Cementitious material and concrete products:

An experimental study was carried out for comprehensive utilization of iron ore tailings in preparation of cementious material. This cementious material was abbreviated as TSC and it was prepared by blending 30 % residues, 34 % blast-furnace slag, 30 % clinker and 6 % gypsum by weight. Further, the raw iron ore tailings (before iron recovery) with TSC1 were selected to compare the cementious property of raw tailings. The results shows that the mechanical properties of TSC1 were well comparable with those of 42.5 ordinary Portland cement in accordance with Chinese GB175-2007 standard (Chao et al. 2010).

Effects of additives on the properties of concrete products made from iron ore tailings were studied by Niu and Chen (2011). Several additives were analyzed so as to improve the properties of the concrete products. The investigation revealed that the fuel additives (FN) significantly improve the early age strength of the products, while positively impacting the final strength when used in low dosage. It was said that this is due to improved hydration properties and formability of the produces when using fuel additives. Similar study carried out by Xiaoqing et al (2011) on effect of additives on the properties of concrete products made from iron ore tailings. Concrete products were prepared by mixing cement and fly ash at appropriate ratios which possess certain compressive and flexural strengths. Iron ore tailings were used as main raw materials to make concrete bricks. It was observed that the concrete products obtained by mixing the iron ore tailings, cement and fly ash at a ratio 65:25:10, the compressive strength achieved was 31 MPa for 28 days curing. The hardness and the strength of the iron ore tailings were lower than the building sands. However, by adding small quantity of FN, the early age strength and final strength of the concrete products made with iron ore tailings can be improved.

Evaluation of the iron ore tailings from Itakpe in Nigeria as concrete material was investigated. The evaluation study carried out by Uchechukwu et al. (2014) used iron ore tailings to replace sand and cement, in proportions of 5 % up to 30 % and cured for a period of 90 days in water. Characterization of the material (IOT) had pozzolanic properties, and can be used as a retarder for hot-weather concreting. Other characteristics of the IOT as sand and cement replacement material in concrete production, exhibited improved workability and higher compressive strengths over the control strength with approximately 10 % and 38 % for sand and cement respectively.

This study also reveals, the linear regression models can be used to predict relationships of IOT-OPC concrete.

2.3 Utilisation of mine / minerals wastes as building materials:

Significant amounts of research have been carried out worldwide in usage of mine waste and tailings for the manufacturing of building materials. The mining waste is generally used as aggregate in concrete and also in manufacturing of bricks, tiles, cement, pozzolana etc. It is also used as pigments for paints. A study carried out by Hammond (1998) stressed that by using mine waste natural resources will be conserved, energy will be saved and environmental pollution will be reduced. The study conducted by Reddy (2004) concludes that there is a large scope for R & D in developing alternative building technologies.

Application of intelligent decision support system for comprehensive utilization of tailings and waste rocks in China and worldwide were developed by Keqing Wang et al. (2011). The idea was implemented and the system was built by combining engineering practice of comprehensive utilization of tailings and waste rocks with other subjects like artificial intelligence, neural-network, fuzzy mathematics and decision making technology. A study carried out by Robert and Richard (2011) on utilization of mining and mineral processing wastes in the United States, describes the principle classifications of solid wastes from mining and mineral processing based on physical and chemical properties of each type of waste material. The principle locations and approximate quantities of each category of mining and mineral processing waste were also included in this study. Pertinent technical, economic and environmental considerations involved in specific uses of these wastes were also discussed. The need for research and efforts involving particular waste material are also documented in this investigation.

2.3.1 Iron ore waste / tailings:

A critical review was carried out on present status of waste-based building materials available in India by Amit and Rao (2005). An experimental study was carried out on the availability of solid waste of mines and quarries as course aggregate in concrete mixes. Possibilities of utilising over screen reject generated during phosphate ore processing and rock fragments of quarrying marble and granite rocks in concrete production as full replacement of natural gravel in concrete mix was investigated. Through the experimental work it was concluded that, the physical, chemical and mechanical properties of the three waste materials used as course aggregate to substitute the natural gravel in concrete mixes are within the scope of requirements. The compressive strength values observed for prepared concrete cubes after 28 days of curing were 18.93 MPa, 25.69 MPa and 26.67 MPa with phosphate, marble and granite aggregates respectively (Mageed Ahmed et al. 2014).

Suitability of iron ore tailings (IOT) in building construction to examine the compressive strength of the IOT concrete for construction work. Analysis made using Minitab software for the statistical analysis was studied. The Results obtained showed that, with increased period of curing ages and an optimal combination of the sand and cement replacement resulted in an optimal high strength of IOT concrete. The quantity of materials utilized for concrete was reduced (sand and cement quantity), and thereby reducing the cost of production and on the other hand reducing the pollution of environment by utilizing the iron ore tailings as building materials. From the analysis of variance it was observed that there is no specific interaction between the factors and their levels but, there is significance in strength of the IOT concrete increasing as curing age increases. Since both sand and cement replacement are of the same percentage (20 %) Lasisi et al. (2014).

Iron ore tailings can also be used as replacement to fine aggregates in cement concrete pavements. The properties of iron ore tailings (from Kudremukh Lakya Dam site) were determined and compared the results with the conventional sand. The strength properties of concrete for 3, 7, 28 and 56 days were also determined. The IOT replacement was in the ratio Mix1 - 10 %, Mix-2 - 20 %, Mix3 - 30 %, Mix4 - 40 % and Mix5 - 50 % and it was observed that replacement of IOT 40 % gives maximum compressive strength (56.59 N/mm^2) is more than the reference mix (41.05 MPa) for 56 days of curing period. It was also observed that reference mix shows maximum flexural strength which is more than the IOT replaced mixes. The number of repetition obtained for Mix-4 was more than reference mix i.e. 0.7 stress ratio (Skanda Kumar et al. 2014).

2.3.2 Manganese residue:

Waste residue produced during the electrolytic preparation process of manganese cause serious environmental problems. Baking-free brick, a promising building material can be produced from manganese slag with addition of quicklime and cement. Several analyses were done by Ping et al. (2013) to measure the physical properties, chemical composition and mechanical performances of the brick samples. The study revealed that the production of electrolytic manganese residue (EMR) baking- free brick, with 25~30 MPa of moulding force was economically feasible and the pressure during forming process was beneficial for obtainment of the brick strength. Baking- free brick prepared from EMR having cement aggregate ratio as 1:1, water solid ratio as 0.15 and the moulding pressure as 30 MPa had excellent compressive strength. The results also showed that EMR-sand-lime-cement production system was the optimum with 50 % of EMR, 25 % of river sand, 10 % quick lime and 15 % of cement.

Similar study carried out on preparation of baking free brick from manganese residue and its mechanical properties by Wang et al. (2013). The mechanical compressive strength observed from bricks made using Electrolytic Manganese Residue (EMR) with cement aggregate ratio 1:1 and water solid ratio 0.15 was 13.5 MPa and 14.7 MPa at moulding pressure 25 MPa with 7 days curing. Similarly, 17.4 MPa and 21.3 MPa at moulding pressure 30 MPa with 28 days curing. The density observed through the study was 1.72. Further, it was also concluded that the 50 % of EMR, 25 % of river sand, 10 % of quicklime and 15 % of cement production system was optimum.

2.3.3 Copper tailings:

A study on utilization of copper tailings in manufacturing of autoclaved sand-lime bricks was carried out by Fang et al. (2011). They used copper tailings, river sand and limestone to prepare bricks. The material was filled into mould of size 10 cm × 10 cm × 5 cm with 20 MPa preload and autoclaved in it. The results of the study shown that the copper tailings when used as main raw material by adding sand increased the content of SiO_2 and hydrated calcium silicate, which gives high strength to bricks and also reduced its weight. The content of copper tailings in the brick does not exceed 50 % and brick was autoclaved at 180 ^{0}C for 7-9 hr. Similar, study was done on copper tailings used to prepare eco-friendly bricks by geopolymerization technology using an alkaline solution by Ahmari et al. (2012). From this study it was observed that the compressive strength of the geopolymer bricks varies from 3.69 MPa to 33.7 MPa at 15 M NoaH concentrations with curing temperature of 90 $^\circ$C for 7 curing days. The water was added at 16 % ratio with 0.5 MPa pressure.

An investigation was carried out by Huang et al. (2012) on autoclaved aerated concrete (AAC) which was prepared using skarn type copper tailing (SCT), blast furnace slag (BFS), quartz sand (QS), cement clinker (CC) and gypsum. The steel moulds of size 100 mm × 100 mm × 100 mm were used to prepare AAC. The raw material was prepared by adding warm water at 48±1° C for 2 minutes and finally aluminum powder was added to the mixture. The samples were unmolded and put into an industrial autoclave for hydrothermal reaction for 8 hour at 13.5 bars pressure. The AAC product with a dry density of 610.2 kg m^{-3} and compressive strength of 4.0 MPa was observed by using raw material composition of 30 % skarn-type copper tailings, 35 % high furnace slag, 10 % cement clinker and 5 % gypsum. The results of investigation revealed that SCT and BFS can be used as substitute for lime to produce AAC products.

2.3.4 Gold mill tailings:

An experimental study on the usage of gold mill tailings as aggregate in construction industry was carried out by Dean et al. (1996) The mill tailings was used in addition to fly ash, Portland cement and water to manufacture concrete blocks and bricks. The concrete cylinder block of size 10.16 cm × 20.32 cm was used to prepare the blocks and observed an average compressive strength of 18.34 MPa. This is almost 40% higher than the American Society for Testing and Materials (ASTM) (i.e. 13.10 MPa). Whereas, brick made with gold mill tailings had strength of 28.22 MPa which is 17 % higher than that ASTM requirement.

A feasibility study was carried out by Roy et al. (2007) on gold mill tailings of Kolar Gold Fields in making bricks using mill tailings with cement as an additive in 5 %, 10 %, 15 %, 20 % and 25 % proportion and cured for 3, 7, 14 and 28 days, and tested as per IS Standards. The results of the study indicated 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) cause deformation problem with black cotton soil. Similarly, cracks were found with red soil after firing when 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. Results of cost analysis study reveals that soil tailing bricks are very economical whereas cement tailing bricks are un-economical.

Similar study was carried out by Yonggang et al. (2011) on fired bricks by using gold mill tailings and clay. The sequence of pretreatment, mixing, ageing moulding, drying, sintering and performance testing was followed in making of bricks. Through this study it was found that the compressive strength can reach the Standard MU10 (Fired Common Brick) when 70 % to 90 % fine tailing is used at 1000° C with 60 minutes holding time.

2.3.5 Tungsten waste:

The tungsten mine waste along with river sand and calcium hydroxide in different ratios were used for manufacturing blocks of 50 × 50 × 50 mm^3 size (as per American Society for Testing and Materials C109). Sodium hydroxide concentration of 24 molar (M) was used as an activator, which gave a compressive strength of almost 70 MPa (in an average of 3 samples). It was also observed that even higher strength performance could be achieved if lower water/sodium molar ratios were used (Feranado et al., 2008).

Similar study was also carried out using tungsten tailing mine waste (TTMW), ground granulated blast-furnace slag (GBFS) along with ordinary Portland cement (OPC) and sand. The blocks prepared were of size 50 × 50 × 50 mm^3. The prepared specimens were cured for 3, 7, 14 and 28 days at 23^0 C. Further, TTMW and GBFS were replaced at ratio 0 % to 30 % and 0 % to 45 %, respectively and tested. Through the results it was found that the mixture is very effective when TTMW is moderately within 10 % of content by mass (Choi et al., 2009).

2.3.6 Quarry residue and waste steel slag:

An experimental investigation was carried out on characteristics of acid resisting bricks which were made from quarry residues and waste steel slag. Bricks were made incorporating kalin fine quarry residue (KFQR) combined with granulated blast-furnace slag and granite-basalt fine quarry residue (GBFQR) to make a brick resistible to chemical reactions, particularly sewage waters. These bricks possess better properties than conventional one. Latest technologies like X-ray fluorescence and X-ray diffraction techniques were also used to carry out chemical and mineralogical analyses respectively. Scanning electron microscope and energy dispersive X-ray analyses are used to study the microstructures of some selected fired specimens. Five suggested batches of solid briquettes namely S1, S2, S3, S4 and S5 were made by including 50 % of KFQR as a constant percentage, whereas percentage of GBFS is increased 10 % to 40 % while decreasing GBFQR percentage from 40 % to 10 %, respectively. In order to assess the physical, chemical and mechanical characteristics of fired specimens, each batch composition was examined against the requirements of Egyptian Standard Specification. The batches from S1 to S4 fired until 1125˚ C found to be utilized for making acid resistance bricks. Batch S2 (50 % KFQR, 20 % GBFQR and 30 % GBFS), fired at 1125˚ C was selected to be the most promising mixture for acid resistant brick industry as it had the most superior ceramic properties (Medhat et al., 2008).

2.3.7 Limestone powder:

An investigation was carried out by Turgut (2010) for making composite material using limestone powder (LP) and fly ash (FA), without adding Portland cement. Limestone powder was mixed with fly ash at various levels 10, 20 and 30 % by volume and compressed under high pressure (20 MPa for 1 min) in steel mould of size 105 mm × 150 mm × 225 mm. The samples were then cured for 90 days. It was observed that 20 % of fly ash is optimal for the manufacturing of blocks and limit values were met according to BS 6073, Society for Testing and Materials (ASTM C 90) and Turkish code TS 705. In addition to that, experiments were conducted in the year 2007 for potential use of limestone powder waste (LPW) and wood saw dust (WSW) mixture together with Portland cement to produce lighter and economical bricks (sizes 105 mm × 90 mm × 75 mm). Brick samples kept in a in a mold for 4 hour under specified pressure. The molded samples were cured at room temperature for 24 hour, further, kept for curing in a tank for 28 days and then dried in a ventilated oven at 105^0 C for 24 hour. The bricks were tested for various mechanical properties. The results of the study shows that the concrete with 30 % replacement of WSW attained 7.25 MPa compressive strength and also this composition is about 65 % lighter than the conventional concrete brick. The result also satisfied the requirements of BS 6073 for building material to be used in the structural applications.

3. Utilisation of fly ash in brick / blocks making:

A study was carried out by Sunil Kumar (2002) on development of fly ash-lime-gypsum (Fal-G) bricks and also hollow blocks by utilizing industrial waste which was found economical. He used these mixtures along with fly ash at 60 %, 70 % and 80 % ratios. The size of brick was 220 mm × 100 mm × 75 mm and that of block was 150 mm × 150 mm × 150 mm. The samples were cured for one week in gunny bags by sprinkling water on it. The samples were then transferred to the tank containing sulfate solution at temperature of 23 ± 2^0 C and then cured for 24, 72 and 96 days. The bricks prepared with the ratio 80:10:10 (i.e. fly ash: lime: calcined phosphogypsum) achieved the compressive strength of 5.9 MPa after 96 days casting/curing, which satisfies IS Standards (13757:1993) of burnt clay bricks (i.e. minimum 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 (13757:1993). Because as per the IS Standards, the water absorption should not be more than 20 % (by weight). Another investigation was done by Freidin and Erell (1995) on manufacturing of bricks by using of coal fly-ash, slag and water-glass cured in the open air for 28 days at 20^0 C – 23^0 C. Two different mixtures were prepared. One was the combination of fly-ash and water glass, which was called as fly ash mixture (FA), another was FAS mixture consists of fly-ash and slag in equal proportion. The results of the study revealed that the compressive strength of bricks prepared by FAS mixture was higher than FA mixture i.e. 2.0 MPa – 20.0 MPa.

One more study was done by Cicek and Tanrıverdi (2007) on manufacture of light weight lime based steam autoclaved fly ash bricks using fly ash, sand and hydrated lime. Twenty two different types of brick specimens were prepared under various conditions, which were of different composition. . From the study it was found that 68 % fly ash, 20 % sand and 12 % hydrated lime mixture is an optimum composition for the bricks. The bricks were prepared by applying 20 MPa pressure with 6 hour autoclaving time and 1.5 MPa autoclaving pressure. Similarly, the Physico-mechanical properties reported were compressive strength 10.25 MPa, water absorption 40.5 %, volume weight 1.14 g/cm^3 and thermal conductivity was 0.34 Wm^{-1}K^{-1}. This study demonstrated that, it is possible to produce light weight bricks using fly ash having low thermal conductivity. This reduces the manufacturing cost as well as recycling of fly ash, and also minimizes its negative impact on the environment.

Experiments were conducted by Rushad et al. (2011) on hand made moulded and pressure moulded fly ash bricks manufactured using lime stone (L), local soil (S) and fly ash (FA) with different proportions. The modular brick samples were prepared in ratios (L: S: FA) 15:5:80, 10:10:80, 25:5:70, 20:10:70, 35:5:60 and 30:10:60. Similarly, modular bricks were prepared with lime and fly ash in the ratio 20:80, 30:70, and 40:60. These bricks were prepared by applying load of 10 kN, 30 kN and 50 kN and all samples were cured by moistening jute bags for 7 and 28 days. With this study it was found that the most of the bricks belongs to Class 3.5 and 5 in respect of compressive strength (IS 13759:1993). But the bricks prepared L & FA in ratio 40:60 satisfies the criterion of Class 3.5 in respect of both compressive strength and water absorption.

An experimental study conducted on cellular light – weight concrete blocks as a replacement of clay bricks. The study shown that the use of fly ash in foamed concrete greatly improves its properties and cellular light weight concrete blocks gives a prospective solution for building construction industry along with environmental preservations. Hence the cellular concrete blocks are recommended as replacement of clay bricks for construction purpose (Krishan Bhavani Siram, 2012). The study of Fly-ash bricks masonry involves in FAL-G brick made out of fly ash, lime, gypsum and quarry dust of size 225 mm x 10 mm x 5 mm were cured for 21 days and tested for water absorption and compressive strength were 15 % and 22.68 N/mm^2 respectively. The experiments were also carried out on FAL-G brick prism masonry using Rat-Trap method and at 14 days compressive strength observed were 88.05 kg/cm^2 for cement mortar (1:6) and 88.83 kg/cm^2 for fly ash mortar (1:6). As an evident of results, it was also reported that the compressive strength can be increased up to 135 kg/cm^2 to 145 kg/cm^2 for fly ash mortar (1:6). Further, it was also found that the masonry work with new technology Rat-Trap bond in fly ash bricks have 33 % saving in cost as compared to common bricks (Mistry et al. 2011).

In India about 54.09 % of electricity is generated from coal based thermal power plants. Out of total fly ash generation of 131.09 million tonnes per annum the utilization rate is 73.13 million tonnes per annum only and un-utilized fly ash is about 922.95 million tonnes from 1996-97 to 2011. These un-used fly ashes will impose an adverse impact on environment and eco system. A study was carried out by Sing et al. (2014) on value added utilization of fly ash- A prospective and sustainable solution. The fly ash is used as adsorbent for various gaseous pollutants like SO_x, NO_x and various metals. Similarly, the fly ash can also be used for removal of phosphate, fluoride, boron, phenolic compound, and mercury. The use of fly ash in different sectors like agriculture 1.02 %, Wetland reclamation 8.2 %, roads and embankments 13.02 %, mine filling 6.7 %, bricks 6.51 % and cement 48.13 % are also highlighted.

Banu et al. (2013) carried out study in making bricks with fly ash-sand-lime and gypsum addition. An optimum mix of fly ash, sand, hydrated lime and gypsum at ratios 55 %, 30 %, 15 % and 14 % respectively, they proved to be optimum for forming pressure 20.68 MPa. It was observed that increased brick forming pressure increases the compressive strength, unit volume weight and decrease in IRA (initial rate of absorption), absorption capacity and open pore volume. For their optimum composition and pressure, bricks exhibited the following properties: no shrinkage, unit vol. weight 1.81 gm/cm^3, initial rate of absorption 14.84 %, absorption capacity 11.58 %, open pore volume 9.23 cm^3 and impervious pore volume 34.74 cm^3. The maximum compressive strength observed for optimal composition and pressure with curing (5 weeks) under spray water twice a day was 442.96 kg/cm^2. It was also observed that the bricks cured in water for four weeks followed by one week in air with 3000 psi forming pressure exhibited maximum compressive strength of 877.36 kg/cm^2.

An experimental investigation was carried by Sumathi et al. (2014-2015) on compressive strength of fly ash brick with addition of lime, gypsum and quarry dust and also to find the optimum mix percentage of fly ash brick specimen of size 230 mm x 110 mm x 90 mm. For preparation of bricks seven different mix proportions were used i.e. fly ash (15 % to 50 %), gypsum (2 %), lime (5 % to 30 %) and quarry dust (45 % to 55 %). The prepared brick specimens were tested for their compressive strength for different mix proportions, at different curing ages (7 days, 5 weeks and 1 week in air a 4 weeks in water). The experimental results reveal that, among the seven proportions the maximum optimized compressive strength is obtained for optimal mix percentage of flyash-15 % lime-30 % gypsum-2 % quarry dust-53 % as 7.91 MPa.

An invention was made by Pimraksa et al. (2001) for manufacturing of bricks made out of 100 % fly ash and its possibilities to use as a building material. The influence of treatment of fly ash i.e., sieved -63+40 micro meter fly ash, sieved -40 micro meter fly ash and ground for 5 h and 10 h, respectively. The bricks made of -40 micro meter fly ash were found superior in mechanical strength (compressive strength) compared to red-fired clay bricks, common bricks and facing bricks used in constructional work. This study also revealed that highest bending and compressive strength can be obtained by using -40 micro meter fly ash as body and fired at 950^0 C is 13.1 MPa and 56.3 MPa respectively. It was also observed that most of the samples had low weight and low shrinkage (not more than 3 % as compared with clay brick).

4. Summary and overall discussion:

It is found from the detailed literature review that there is a lot of scope for utilization of mine waste/industrial waste in the construction industry in the form of manufacturing of bricks, paving blocks, tiles etc. This not only helps in utilization of huge waste generated during mining of minerals and any other engineering activities, but it also helps in restoring land and maintaining aesthetic beauty of the nature, which will also reduce land degradation, water and air pollution. Further, there is a lot of scarcity of aggregates particularly sand for the construction industry, which is going to be acute in the future. In view of the above circumstances, the mine waste/tailings produced from the mines/beneficiation plants can be a very good alternative material for the construction industry. Further, to fulfill the market demand and to find an alternative material for the construction industry, as well as to conserve the environment, it is very much essential to utilize mine waste/plant tailings/industrial waste as one of aggregates in manufacturing bricks.**5.0**

Conclusion:

Utilizing waste for the production of building material is considered to be important for conservation of natural resources and reduction of environment pollution. Manufacturing of building bricks without burning of solid fuel is one of the options for reducing the emission of CO_2 gas. If the waste material is dumped in a site, the flow of material during rainy season creates a lot of loss for the fertile land, so the waste utilization plays the vital role in natural resource conservation. Utilization of mine waste in the construction industry is 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. Various researchers have proved that waste generated from various mines/quarries, like iron ore, lime stone, copper, tungsten, gold, granite etc. can be effectively used in the construction industry. As India is one of the major producers of iron ore, huge waste from iron ore mines is dumped in large areas in the form of overburden and tailings. The recycling or re-usage of these wastes is very much important in view of restoration of land for its effective utilization. In this regard it is very much necessary to intensify research in this area for making use of these wastes in the form of bricks/paving blocks/tiles etc.

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