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Abstract: Utilisation of iron ore tailings in bricks as a replacement for sand will help in sustainable and greener development. The literature shows the potential use of iron ore tailings as a replacement of natural fine aggregates. As natural sand reserves are depleting day by day, there is a need for substitution for sand in bricks. A comprehensive overview of the published literature on the use of iron ore tailings and other industrial waste is being presented. The effects of various properties such as compressive strength, thermal conductivity and durability of bricks have been presented in this paper.

Keywords: iron ore tailings; IOT; bricks; compressive strength; thermal conductivity; greener development.

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1 Introduction

Bricks are widely used in the construction of buildings and other infrastructural facilities. Bricks are produced using clay and sand as the raw material and burnt in kiln at high temperature of 900° to 1,000°C. It is one of the primary building materials known to mankind. Over time, bricks have appeared, gained prominence, lost importance and again then come to forefront in various modes of architecture. Burnt bricks were used in ancient India, Babylon, Egypt and Roman civilisations (https://www.ecobrick.in). They are still being used as filler materials for framework structures as well as to construct load bearing structures. The processes of making a brick traditionally are material tampering, moulding, drying, firing and sorting (Figure 1). Bricks are burnt in intermittent kilns or continuous kilns (Figure 2).

Figure 1 Process of making bricks (see online version for colours)

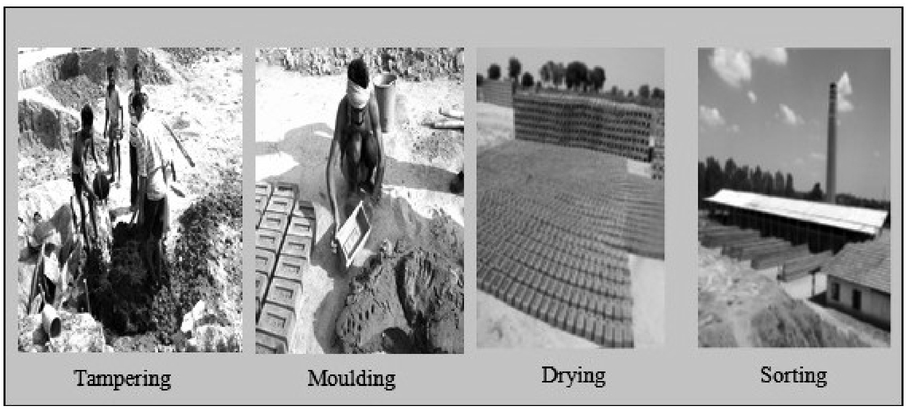
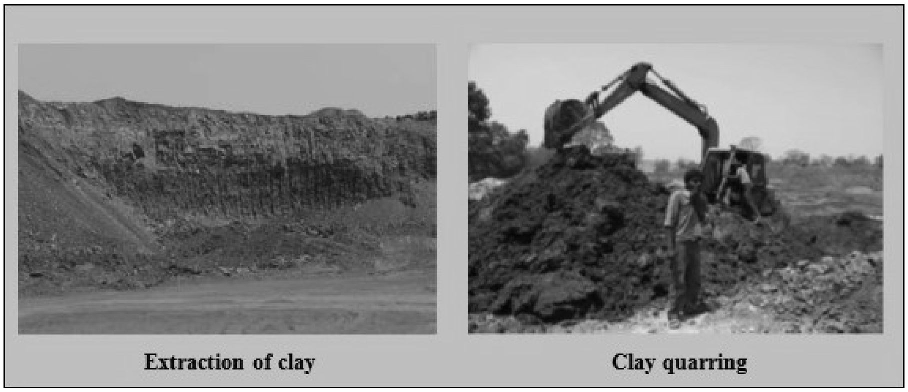


Figure 2 Kilns for burning bricks (see online version for colours)

India is the second largest brick producer after China in the world. Annual brick production in India is 240–260 billion and clay consumption is 500 million cubic metre. CO_2 emission from these clay production units is 66 million tons (https://www.cseindia.org/dev/add2015). In general, the raw materials for production of bricks are clay and sand, which requires a considerable amount of energy in quarrying them. Clay quarrying adversely affects the landscape and produces some waste material (Figure 3). The kiln firing consumes significant amount of energy and release huge quantity of green house gases.

Figure 3 Clay mining (see online version for colours)



Along with clay, sand is another essential commodity in making bricks. The sand being natural resource, which is of depleting nature, so the sustainability is the main criterion in today's scenario, posing a challenge not only to the construction industry but also for entire infrastructure industry. It has resulted in the acute shortage of fine as well as coarse aggregates, urging to explore the alternative material for partial replacement for sand and other construction materials without compromising the quality, economy and environment. In such case, the use of any industrial waste in the construction results in reduced use of natural resources.

Figure 4 A real view of an iron ore mine (see online version for colours)

On the other hand, the industrial waste always causes pollution and their disposal is a problem for the concerned authorities because either they occupy a lot of space for storage or they pollute the media in which they are disposed. The mining industry is one source of such waste generation. Mine waste available after the extraction of useful ore as an alternative for construction materials.

Among the various minerals mined, iron ore is one of the largest in quantity in many countries. Generally iron ore mining is done using surface mining method (Figure 4). This ore is normally rich in iron oxides and vary in colour from dark grey, bright yellow and deep purple to rusty red. The iron is usually found in the form of magnetite, hematite, goethite and limonite.

World production averages two billion tons of raw ore annually. China followed by Australia, Brazil and India are the four top ranking iron ore producing countries in the world (Table 1). China produced 1.3 billion tons of iron ore in 2015 equivalents to 44% of the world's production (https://minerals.usgs.gov/ironore).

Table 1 Major iron ore producing countries in the world

Rank	1	2	3	4	5	7	6	8
Country	China	Australia	Brazil	India	Russia	South Africa	Ukraine	USA
Iron ore production in 2015 (Mt)	1,381	817	389	156	101	73	67	43

The total recoverable reserves of iron ore in India are about 5,422 million tons of hematite and 53 million tons of magnetite. Iron ore production in the year 2015–2016, in India was 156 Mt (Indian Mineral Yearbook, 2016).

The iron and steel industry in India contributes around 2% of gross domestic product (GDP) (Settu and Padhmanaban, 2016). The mine-head closing stock of iron ore for the year 2016–2017 was 148.42 million tonnes as compared to 144.50 million tonnes in 2015–2016 (Indian Mineral Yearbook, 2017).

Any structure designed intelligently and responsibly requires to be as light as possible. The function is to support live loads. The dead loads, of the structure itself are a necessary evil. The smaller the ratio between a structures dead load and the supported live load, the lighter the structures are. For ecological, social and cultural perspective, light weight structures have never been more contemporary and necessary than today. The use of bricks as void filler in the framed structure, has given rise to the concept of reducing the dead load in the buildings. The bricks made of iron ore tailings (IOT) (Figure 5), will have higher density because of iron content, which needs to be reduced without hampering the required compressive strength and other physio-chemical properties. Hence, a light weight additive to be added to reduce the density. Expanded perlite (EP) is one such additive which has very low density of around 0.06 gm/cc, which can be used to reduce the weight of bricks.

Perlite is an amorphous volcanic rock that has relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its low density after processing. Perlite softens when it reaches temperature of 850–900°C. Water trapped in the structure of the material vaporises and escapes, and this causes the expansion of the material to 7–16 times of its original volume (Indian Minerals Yearbook, 2015).

Unexpanded perlite has a bulk density of around 1.1 gm/cc, while typical EP has a bulk density of about 0.03–0.15 gm/cc. Because of light weight and better insulating characterisation of perlite, it is used in light weight concrete, loose fill masonry insulation, chimney linings, etc. The use of perlite in bricks may act as density controller and results in many other advantages like heat insulation, light weight, acoustic insulation properties etc.

Figure 5 Bricks with IOT, sand and cement (see online version for colours)

2 Literature review

The current trend all over the world is to utilise the treated industrial by-products as a raw material in the construction, which gives an eco-friendly solution to waste disposal. To achieve this objective, intensive efforts are under way in effective utilisation of industrial by-products particularly from mining and mineral industries. The role of additives will enhance the physico-mechanical properties of the materials, adhering to standard recommendation to the construction. The brick size of 230 mm × 112.5 mm × 75 mm is the standard size in construction and compressive strength of 3.5 N/mm^2 to be achieved as per IS code 1077:1992 of burnt clay bricks (i.e., 3.5 N/mm^2) and water absorption shall be less than 20%.

2.1 IOT in construction and manufacture of bricks

In recent years, utilisation of IOT has got much global attention, especially in construction. This practice can help to reduce the emission of greenhouse gases, by avoiding the emission of virgin engineering materials, providing cheaper alternative materials for building and constructions and for natural resources conservation.

Iron ore is being beneficiated around the world to meet the raw material requirements of the iron and steel industries. The specific beneficiation process is selected for optimum product extraction depending on the nature of the gangue and its association with the ore structure. The prime function of beneficiation of the iron ore in India is to improve the content of extracting iron and reduce the Al-Si content of the finished iron. Iron ore beneficiation proceeds mainly from washing, sizing classification, jigging, magnetic separation, froth floatation, etc.

The advantage of washing is to impact better handling properties to the ores, particularly the removal of fines, which becomes sticky in rainy season and may pose problems during transportation. After beneficiation, once silica and aluminium bearing metals are removed by washing, rejected portion of iron ore may include coarse and fine particulates in the wash water forming slurry known as wet tailings, which will be stored in ponds of disposal of tailings (Figure 6).

The waste/tailings that are ultra-fines or slimes, having a diameter less than 150 µm, are not useful and hence are discarded. In India approximately 1,500–2,000 million tons of such mined ore is lost as tailings. The safe disposal or utilisation of such vast mineral wealth in the form of ultra-fines or slimes have remained as a major unsolved and challenging task for Indian iron ore industry (Mohanty et al., 2010).

Figure 6 A view of a typical tailings pond (see online version for colours)

Disposal of mine tailings is the major task demanding high cost for the steel plants. Such waste material pollutes the environment and causes lot of issues connected to its storage and handling. Tailings have many adverse impacts on the environment like pollution of ground water, soil erosion, loss of biodiversity, soil contamination, infertility of soil, acid mine drainage, etc. The use of such tailings as construction material has double benefit of reduction in the cost of the product and safe disposal of tailings safeguarding the environment. One such usage can be in manufacture of building bricks and other value added products without burning of solid fuel, which helps in reduction of CO_2 emission and saves natural resources like sand and clay.

Conventional method for manufacturing of bricks is to produce bricks of sand – clay mixture, which is then fired in a high temperature kiln, which is not considered to be environmentally friendly. The green movement has greatly influenced the design and construction of the built infrastructure across the globe. There is growing interest in building that integrates and optimises all the major high performance building attributes, including energy efficiency, durability, life cycle performance and occupant productivity (Namratha et al., 2014).

2.1.1 IOT as a replacement for sand in bricks

Various researchers have carried out investigations to replace the sand with IOT. Yisa et al. (2016) investigated the compressive strength of laterite bricks with IOT of 250 gm, 500 gm and 750 gm mixed with a fixed quantity of soil, i.e., 2,000 gm from Zaria of Nigeria and arrived at a conclusion that the compressive strength of laterite mix containing varying weight of IOT had higher strength value of 27 N/mm^2 when compared with only laterite which has a compressive strength of 14 N/mm^2 for seven days curing. Compressive strength of laterite bricks with IOT mix increased with increase of IOT content compared to laterite.

Modi et al. (2017) determined the compressive strength of bricks manufactured with iron ore waste, sand and cement in four different ratios. In this study, bricks with iron ore waste substituted for sand showed better compressive strength without much water absorption. The mixture made of cement, sand and iron ore waste with the ratio 30:30:40 and with 28 days curing period, attained a compressive strength of 42.98 MPa and water absorption was 2.42%. This property met the requirements of IS 2180–1988 specification for heavy duty burnt clay building bricks in terms of compressive strength and water absorption.

Ullas et al. (2010) determined water absorption of stabilised mud blocks (SMB) replaced by IOT is more, but well within limits, i.e., 12.13–15.07% because of increase in voids due to higher fine fraction. There is no linear expansion when IOT is used. There is a negligible fall of wet compressive strength of brick, when IOT is used and it is only the difference of 0.25 MPa when 100% sand is replaced by IOT.

Chen et al. (2011) determined the microstructure of fractured surface of the dried specimen without firing the bricks shown compact microstructure and sheet like appearance of phyllosilicates and after firing to 1,000°C for two hours; clear evidence of vitrification which was the typical grain and bond microstructure and crystalline phase were embedded in a glassy matrix forming strong entirety, which promoted the strength of the brick. The compressive strength in natural curing of finished brick was 15.9 MPa with ratio of tailings:cement:sand:gypsum = 78:10:10:2 with 15% forming water content. The strength of bricks decreased when IOT content was over 78%. The microstructure of the brick revealed the compact microstructure of sheet appearance of phychorilicates and the granule silica and hematite. Compressive strength attained high at 40°C, i.e., 17.6 MPa and by further increasing the temperature compressive strength got reduced as shown in Table 2.

Zhao et al. (2014) investigated the use of natural aggregates in incremental percentage replacement by tailings, which reduced the compressive strength significantly and affected the workability greatly. When replacement level is within 40%, the behaviour is comparable to that of control mix and specimen are steam cured for two days, the compressive strength of IOT mixes decreased by approximately 11% while the flexural strength increased up to 8% when compared to the control mix. Adding IOT into the mix, lowered the flowability, increased the water demand due to its high specific surface area and had rough surface.

Table 2 Effect of curing conditions on compressive strength of bricks

Curing condition	*Natural curing*	*Curing temperature (°C)*			
		30	*40*	*50*	*60*
Compressive strength (MPa)	15.9	16.3	17.6	14.3	13.6

Carrasco et al. (2013) studied bricks made of iron ore by-products and cement, stated that the bricks gave high mean compressive strength of 14.57 MPa, with a relatively low coefficient of variation 13.6%. The two overlaid bricks, called prism also showed high compressive strength, a mean of 9.82 MPa relatively with low coefficient of variation 13.1%.

Nagraj et al. (2016) conducted an exploratory study on compressed stabilised earth blocks (CSEB) utilising various proportions of mine spoil waste (MSW) (accumulated at up steam of mining area at Sandur region, Karnataka), quarry dust and stabilisers (cement and lime). MSW utilised in three possibilities 30%, 40% and 50% with cement and lime as a stabiliser in two combinations like 6% cement + 2% lime and 8% cement + 2% lime in CSEB blocks (Table 3). It was observed that wet compressive strength for any combination of admixture is more for blocks prepared with 40% MSW, which indicates these blocks can be effectively used as eco-friendly bricks in construction industry.

Skanda Kumar et al. (2014) analysed replacement of 40% IOT in cement concrete pavement, which gave maximum compressive strength, i.e., 56.59 N/mm^2 (Table 4) and graphically shown in Figure 7. With the increase of IOT, workability reduced. Reduced flexural strength for IOT replaced mixes. Ultrasonic pulse velocity showed a higher velocity which meant more dense, uniform and homogenous for concrete with IOT.

Kuranchie et al. (2014) investigated the strength of the geopolymer bricks made from IOT and sodium silicate (Na_2SiO_3), including UCS, durability and electrical resistivity. The strength of the geopolymer bricks made from IOT with sodium silicate solution is influenced greatly by the curing temperature. The UCS increased as the curing temperature increased to a certain optimum point (80°C) and then the UCS decreased as the temperature increased further (Figure 8). The optimum base parameters for the production of the geopolymer bricks are sodium silicate solution content of 31%, initial setting time of 15 min and curing temperature of 80°C. The electrical resistivity of geopolymer bricks is lower than the commercial clay bricks due to the high iron content associated with IOT. However, the electrical resistivity of the geopolymer bricks is still high enough to be used for building construction.

Table 3 Proportion and combination of stabilisers, iron mine spoil and quarry dust used in the preparation of CSEB's

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

Table 4 Compressive strength of different percentage of IOT mix

Composition	*Compressive strength in N/mm²*			
	3 day	*7 day*	*28 day*	*56 day*
NC	23.83	27.17	38.58	41.05
Mix 1 (IOT 10%)	23.03	32.92	49.28	50.22
Mix 2 (IOT 20%)	21.65	34.15	50.27	53.13
Mix 3 (IOT 30%)	24.27	35.02	51.59	55.13
Mix 4 (IOT 40%)	26.08	32.48	55.10	56.59
Mix 5 (IOT 50%)	25.94	38.91	53.76	54.10

Figure 7 Compressive strength developments of different mixes (see online version for colours)

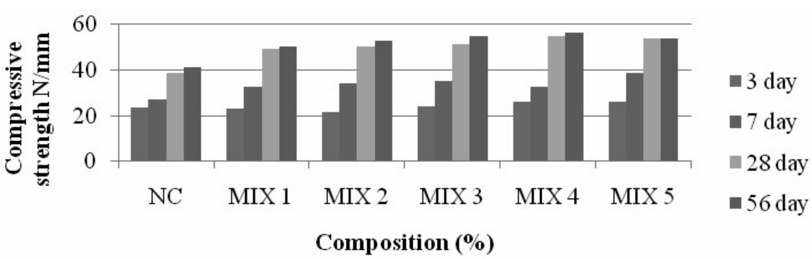
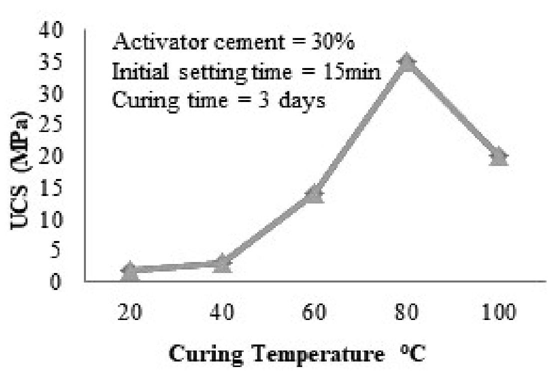


Figure 8 Variation of UCS vs. curing temperature (see online version for colours)



Prahallada and Shanmuka (2014) studied on stabilised IOT blocks showing an increasing trend in the erosion resistance with increase in curing period. Stabilised IOT blocks showed decrease in liquid absorption with increased stabiliser percentage and curing period, i.e., 1.35% on 21 days curing of 7% cement stabilisation. The maximum dry compressive strength of IOT blocks with 7% cement stabilisation on 21 days curing is 8.5 N/mm^2 and the ratio of wet to dry compressive strength lies between 0.5 and 0.73.

Raheem (2006) has assessed the quality of sandcrete blocks and indicated that the compressive strength of the blocks generally ranges from 0.53 N/mm^2 to 1.7 N/mm^2 for 9" blocks, while that of 6" blocks increased from 0.53 N/mm^2 to 1.59 N/mm^2 which is below standards but it was identified that the compressive strength of a sandcrete materials increases with cement content.

Abdulrahman (2015) produced sand-concrete blocks with mix ratio of 1:6 (one part of cement to six parts of sand) where sand portion was replaced by IOT at different percentages like 10%, 20% and 30% at 28 days curing, compressive strength approached the recommended strength for 9" blocks and proved that there is a way for waste disposal (IOT) and development of eco-friendly sandcrete blocks.

Kumar et al. (2006) investigated the use of fly ash, blast furnace slag and IOT in the production of floor and wall tiles. Different percentages of IOT were tried with fly ash and blast furnace slag and proved fly ash, blast furnace slag and IOT in suitable combination in ceramic tiles will improve their qualities including scratch hardness more than six on Mohr's hardness scale and flexural strength more than 25 MPa.

Huang et al. (2013) developed green engineered cementitious composite (ECC), replacing cement by less reactive IOT, reduced the matrix fracture toughness. ECC will be of less compressive strength when replacement ratio is beyond 40% by IOT for cement. Mechanical properties and material greenness of ECC containing various proportions of IOT were investigated. IOT used in powder form with the intention of enhancing the environmental sustainability of ECC. The ECC developed in this study, with a cement content of 117.2–350.20 kg/m^3 has tensile ductility of 2.3–3.3%, tensile strength 5.1–6 MPa and compressive strength of 46–57 MPa after 28 days. The replacement of cement with IOT resulted in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emission compared with typical ECC.

Ugama and Ejeh (2014) studied the suitability of IOT as fine aggregate for replacement of sand in masonry mortar and found compressive, tensile and flexural strength of 36.95 N/mm^2, 1.76 N/mm^2, 5.73 N/mm^2 respectively for optimum level of 20% of IOT replacement (Figure 9).

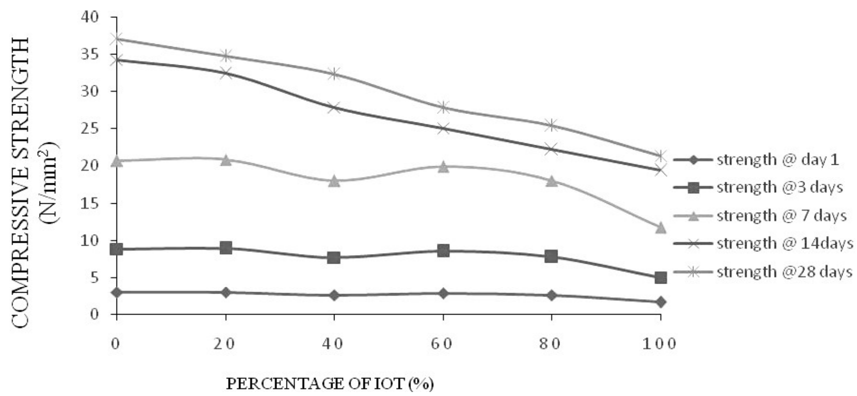
Abdulrahman (2015) determined compressive strength of sandcrete blocks for replacement of sand by IOT and found compressive strength increased with curing age. Compressive strength of sandcrete blocks increased when IOT percentage of replacement was increased.

Yang et al. (2014) investigated the manufacture of light weight aggregate by the mixture of the low silicon IOT, fly ash and powdery quartz sand. The SiO_2 content in the IOT is lower than the requirements for light weight aggregate, while the fluxing content in the IOT is higher than the requirement for light weight aggregates. So fly ash and powdery quartz sand were used as additives in this study to adjust the chemical composition of the IOT. The mixture of all showed good bloating behaviour during sintering. The loose bulk density and the apparent density of the products were well below the required density for lightweight aggregates.

Lightweight aggregates can be formed in a ceramic process in which materials that have the ability to expand rapidly heated at high temperature. Manufacturing of light weight aggregate through the IOT is not only a useful alternative to the extraction of natural aggregates, but also helpful in recycling of the industrial waste.

Likhith et al. (2017) evaluated the raw material of building blocks by utilisation of IOT of size 40 cm × 20 cm × 15 cm for M10, M15 and M20 mix and found compressive strength for seven days are 6.2 MPa, 7.03 MPa, 9.58 MPa for M10, M15 and M20 mix respectively.

Figure 9 Compressive strength of mortar with quality of IOT (see online version for colours)



2.1.2 Energy consumption in the production of bricks

The embodied energy of the brick is the sum of all the energy required to produce the bricks, in all processes from quarrying of clay to firing of bricks. Energy inputs usually entail greenhouse gas (GHG) emissions. It decides how much brick production contributes to global warming. The embodied energy is measured in MJ/kg. A non-fired brick has the advantage of lower embodied energy and in-turn lower GHG emission.

Michael et al. (2009) surveyed on the energy consumption and the greenhouse gas emission during clay brick production in USA. Embodied energy for common clay was about 9.3 MJ/brick. The greenhouse gas emission per common clay brick fired using fossil fuel is around 0.6 kg of CO_2 to the atmosphere, whereas one common concrete brick emits 0.3 kg of CO_2.

Gonzalez et al. (2011) highlighted about the environmental contamination represented by the enormous emissions of greenhouse gases (GHG) resulting in unusual climate changes as smog, acid rain and global warming. Hence, recycling the wastes in the brick production appears to be a viable solution for not only to environmental pollution, but also an economical option to design green buildings. However, the chronic problem of GHG and energy consumption has not yet been tackled properly as many of the previous research works were mainly focused on recycling the waste traditionally in the bricks. Research towards developing eco-friendly bricks in an economical, environmental concern are needed.

Toledo et al. (2004) analysed the gas release, crystalline structure and ceramic properties formed during firing of clay raw materials and extruded bricks. CO, CO_2 and NO_2 and methane emission were measured during the firing cycle and found CO_2 emitted from the powder was 8,600 ppm and from the extruded samples was 6,500 ppm, CO emission was found to be 1,100 ppm from the powder and 800 ppm from the brick and with some minor emission of NO_2 and CH_4. With non-fired IOT bricks, these problems related to environmental degradation are avoided. But IOT bricks are denser in general and the density is to be reduced to some extent using some additives. Perlite is a such additive which can reduce density of IOT bricks.

2.2 Perlite as density controller

Raw perlite when heated to temperature above 870°C expands and transform into a cellular material of low bulk density. This expansion process combines due to the presence of 2% to 6% water in the crude perlite rock. Upon rapid heating, water held within the perlite vaporises and creates bubbles in the heated softened rock. During this process, perlite expands up to 15–20 times of its original volume and produces frothy like micro structure (Figure 10). This microstructure gives the material a set of favourable property such as better insulation properties, low density and high porosity causing EP as one of the most popular light weight mineral filler (Sengul et al., 2011).

Bulut (2010) stated that perlite has chemical inertness, fire resistance and high absorption of sound. All these properties make perlite a usable material for many applications. The EP can be used in the construction industry, horticulture market, as a filter aid and filler. This light weight filler is used as an insulating cover on the surface of the molten metal to prevent excessive heat loss during delays in pouring, to top of ingots, to reduce piping and to decrease lamination, to produce refractory blocks and bricks or simply as fillers and in several important foundry applications.

Major world perlite producers include Greece, China, Iran, Turkey, the USA and Japan. The world production of perlite in 2014, in respect of principal countries was 4.87 million tonnes. As per the Ministry of Commerce, the total imports of perlite in India during 2014–2015 and 2015–2016 was 41.53 and 43.57 tonnes respectively (Indian Mineral Yearbook, 2015).

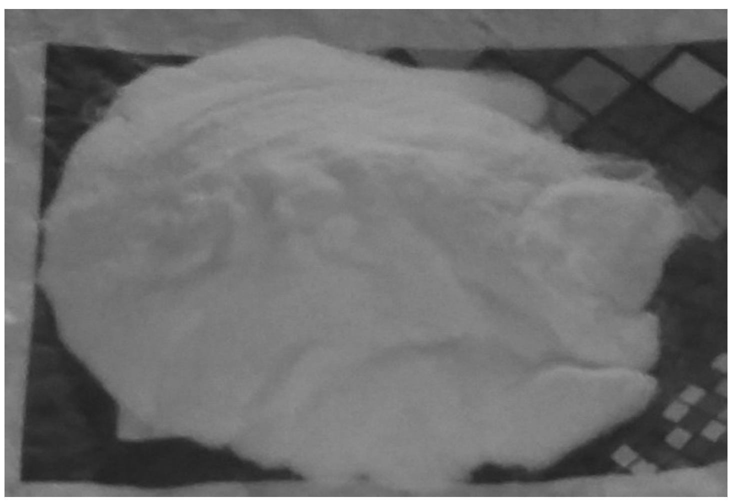
The only deposit of perlite in India is located in the village Patanvav, Rajkot district, Gujarat. It is found to occur in Osam Hill in the form of discontinuous sill. The total resources of perlite as per National Mineral Inventory (NMI) database, based on UNFC system as on 2010 had been estimated as 2.41 Mt, out of which 12% are high grade, 12% medium-grade, 6% low-grade and the remaining 70% fall under unclassified category (Indian Mineral Yearbook, 2015).

One of the main problems associated with the production of EP is formation of relatively large quantities of fine fraction (about 5–10%) with a particle size below 200 m. The resulting lightweight waste due to a large specific surface area and dustiness is very difficult to dispose, especially in dry conditions and so far did not find effective applications. EP is fire, heat and chemical resistant material that have porous structure. Porous structure gives perlite volumetric and surface absorption capability. To prevent water pollution and to ensure insulation, water absorption is involuntary, because pores filled with water increase heat conductivity. Porous structure gives perlite surface absorption and lightweight property. The unit weight of perlite depends on gradation and expansion. The heat conductivity of dry perlite that has a unit weight of 90 kg/m^3 is 0.04

W/mK at 24°C according to dry unit weight method. Chemically, perlite ore consists of SiO_2, Al_2O_3, and lesser amounts of several metal oxides (sodium, potassium, iron, calcium, and magnesium) and therefore can be an attractive addition in many of the building materials like concrete, brick, etc., because of its excellent insulation properties and relatively high compressive strength despite a very low bulk density (Samar and Saxena, 2016).

Energy consumption has been increasing rapidly worldwide due to strong growth in population and industrialisation. Buildings are responsible for about 40% of total energy consumption and one third of greenhouse emissions in the world. Pure thermal performance of building envelope structure is the main cause of energy consumption in buildings. In a typical house, external walls account for approximately 30% of total heat loss which requires an effort to improve heat insulation performance of each wall components (Arici et al., 2015). Perlite bricks can be used in the walls to reduce the heat transfer through bricks by conduction, convection and radiation. The use of perlite in the bricks is initiative to green building concept having long-term benefit of sustainability (Samar and Saxena, 2016).

Figure 10 EP for use in bricks (see online version for colours)



2.2.1 Use of perlite in bricks

Arun Raja et al. (2017) investigated mechanical properties of lightweight bricks using perlite and lime. The specimen size was 190 mm × 90 mm × 90 mm. These bricks were made of perlite and lime in various ratios like 70:30, 75:25, 80:20 and 85:15. They were tested for compressive strength and found it as an average of 3.3 N/mm^2. This work effectively converted perlite into useful building materials.

Demir and Orhan (2004) investigated on the production of construction brick with perlite addition. Thermal conductivity values of sample drastically decreased with increase in amount of EP. Compressive strength with the addition of 5% perlite is 8.72 MPa compared to bricks without perlite 9.25 MPa is less but it is higher than the standards.

Topcu and Isikdag (2007) studied on manufacture of high heat conductivity resistant clay bricks containing perlite. When the replacement ratio of perlite increased, compressive strength decreased, heat conductivity resistance and shrinkage of perlite brick increased.

Celik (2014) investigated the utilisation of EP aggregate as the main raw material. In additional carboxy methyl cellulose (CMC) as a chemical binder, potassium and sodium borate were used as natural binder and coal powder as an additive. Samples were cured at 400°C for two hours. The results indicated the unit weight between 520–580 kg/m^3 and compressive strength as 23 kg/cm^2. Thermal conductivity fluctuated between 0.09 to 0.123 W/mk. Perlite bricks with Na or K borate averted harmful sunlight and radiations by its higher neutron absorbility. The percentage of loss was 19–20%.

Sadik et al. (2013) produced porous fire brick from mixture of clay and recycled refractory waste with the EP addition. Lightweight refractory with the addition of 30% EP increased the porosity of the brick to 65.8% and reduction of density to 1.55 gm/cm^3 (Table 5), having good capacity of thermal and sound insulation.

Table 5 Test results of the brick with EP added to the mixture

Physical properties	*Mass ratio of expanded perlite addition*			
	0%	*10%*	*20%*	*30%*
Bulk density (g/cm^3) ASTM C373-88	2.15	1.95	1.72	1.55
Apparent porosity (%) ASTM C373-88	9.8	51.5	57.5	65.8
Water absorption (%) ASTM C373-88	6.2	28.7	31.8	35.1
Shrinkage (%) ASTM C326-03	5.5	5.6	5.8	6.1
Flexural strength (MPa)	71.41	65.8	53.6	42.7

Arici et al. (2015) investigated on heat insulation performance of hollow clay bricks filled with perlite. Results show that filling with perlite inhibits correction and radiation in the cavities. Hence, effective thermal conductivity reduces significantly for all types of brick. The enhancement of heat insulation performance can be up to 15.6% and 27.5% for half perlite and full perlite cases respectively.

Jedidi et al. (2015) experimented on the effects of EP aggregate dosage on the compressive strength and thermo-physical properties of lightweight concrete at different ages, where six cubes and six sets of parallel piped specimen were prepared at w/c ratio 0.7 replaced with varying percentage of sand by EPA ranging from 0% to 80%, has given unit weight varied between 560 kg/m^3 and 1,500 kg/m^3. Compressive strength decreased with increase of perlite and thermal insulation properties were found to be improved.

Mohajer et al. (2014) studied on light weight refractory insulation panels on the basis of perlite 30% with chemical bonding (H_3PO_4) showed sintering behaviour is the key to achieve the right balance between the low density, which is the basis for good thermal insulation properties, good mechanical properties and durability, saving the energy that escapes from the industrial furnaces.

Sengul et al. (2011) used perlite instead of fine aggregate with various replacement ratios depending on required strength. Test results indicated the compressive strength and modulus of elasticity, decreased with increasing perlite content in the concrete mixture. Moreover, water absorption and sorptivity coefficient increased with the higher perlite contents. Replacing normal aggregate by expanding perlite reduced the thermal conductivity of the mixtures as a result of the porous structure of the perlite.

Benk and Coban (2012) studied the production of lightweight, heat insulating and water resistant bricks from lightweight aggregate like pumice and EP. The raw pumice was poured into the water and then floated aggregates were selected for the mixture. The floated pumice was dried and crushed with respect to pass through 1mm sieve. Crushed pumice was mixed with perlite borax and with a blend of molasses and hardener. About 40 bricks were prepared from three types of mixtures. Each brick was fabricated by compressing 20 gm of the mixture in 23 mm internal diameter steel mould.

The mix design containing 20% EP, the amount of mixture was diminished to 10 gm. Heat treatment applied was 200°C for two hours, then 650°C for one hour and last specimen were cured at 825°C for one hour. Results showed that the hardened molasses bonded bricks should be preferred. When 2.5% borax was not used in the mixture, considerable reduction in tensile strength of bricks was occurred by alteration of replacement ratio of perlite with pumice.

These above literatures gives the road map gor using IOT in bricks, autoclave blocks, concrete, pavements with an advantage of sustainability of environment, waste management simultaneously enhancing the properties of construction materials. Use of perlite has given a way to have light weight blocks and materials with the benefit of thermal conductivity and electrical resistivity sustaining as per IS code strength at a particular replacement percentage.

3 Conclusions

The literature review discussed in this paper gives detailed information about the scarcity of natural resources for making bricks and the requirements for alternative materials, especially from industrial waste. The waste produced in iron ore processing can be effectively used in brick making and use of perlite waste also found to be effective as a density controller about the combination of IOTs along with perlite in brick making and obtaining quantitative satisfactory results is the research work of the first author.

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