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4 Experimental Study on Iron Ore Tailings as Aggregate in Development of Bricks and Concrete

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ABSTRACT

The present study focuses using iron ore tailings in construction. The construction industry is in need of easily available, economically feasible and green materials. This chapter deals with the study of manufacturing bricks and concrete made from iron ore tailings and a few studies were carried out using additive like perlite. The physical and chemical properties of the materials used in the study were determined as per Indian standards and the strength properties were determined. Initially, it was found that, Iron Ore Tailings (IOT) made bricks were found to be denser but after adding perlite the density of bricks decreased considerably and the optimum strength was observed with the addition of perlite by 5% with IOT at 50%. In case of IOT concrete mixes, slump value of concrete reduced with increase in perlite content. The optimum strength of concrete was 51.00 MPa with IOT-alccofine-perlite at 30-10-2.5%. Hence, bricks and concrete can be produced by replacing IOT without compromising the strength and durability properties and also helps in greener environment by utilizing the waste produced at mine sites, which also avoids dump maintenance issues.

Keywords: Bricks, Concrete, Compressive Strength, Iron Ore Tailings, Perlite

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1. INTRODUCTION

The iron ore production is 3,332 million tonnes compared to the previous year by 3,317 million tonnes [1]. In the process of extraction of a large quantity of ore, a lot of waste is generated and dumped which are called overburden dumps. The ore is processed in plants, the waste generated from such processing in the iron ore industry is Iron Ore Tailing (IOT). India produces millions of tonnes of IOT and disposal of it could be immense downside and it causes environmental pollution. However, there is a negative impact on the atmosphere due to mining of iron ore and subsequent generation of iron ore waste and tailings. Therefore, utilization of tailings as a building material has a merit of minimizing the cost of the merchandise and discarding of tailings preserving the environment [2].

Construction industry mainly uses bricks and concrete for building infrastructure. The raw materials used are clay, sand, cement and aggregates. In case of bricks, they are of two types, namely fired and non-fired bricks. To make green buildings, bricks are to be prepared without burning. In India, burnt clay bricks are substantially used as construction material [3, 4]. Another material used in construction industry is perlite [5, 6]. The commercial product is produced by heating approximately to 800 – 850^{o}C. Due to perlites lightweight property, it has very low density, which may be accustomed to scale back the load of bricks. Unexpanded perlite incorporates a bulk density around 1.1 gm/cc, whereas bulk density of typical expanded perlite is 0.03-0.15 gm/cc [7]. In building construction, perlite powder is used as loose fill insulation, because it enhances fire levels and reduces noise transmission to buildings [8]. China, Greece, Italy, Turkey and USA are the leading producers of expanded perlite [9].

The exploitation of natural resources uplifts the economy and society, but on other side it additionally generates large impose, mill tailings, silt etc. which contaminates the surroundings deeply. Therefore, comprehensive utilization of waste/tailings is vital. To construct each tiny and enormous structure owing to its structural versatility, brick masonry is widely used. So as to cater to the various needs of construction, varied bricks are developed and used [10].

A study was conducted with a purpose of determining a potential resolution for better use of Iron Mine Spoil Waste (MSW) piled up as silt within the upstream portion of a dam. By utilising MSW, cement and lime different attempts are created by varying the amounts of MSW (30 % to 50%) during this study in preparation of Compressed Stabilised Earth Blocks CSEBs, it was concluded that blocks have less than 5MPa compressive strength at 6 months of ageing. Hence it results in green building blocks contributing to sustainable environment [8].

Experimental investigation on steel slag and iron ore tailings to produce solid brick was considered. The bricks were produced by adding the cement at 0 and 5% with mixing of different compositions of the residues. Flexural strength of bricks obtained was greater than 2.0 MPa and hence the weight of bricks were similar to ecological bricks [9].

Experimental study on interface behaviour of masonry structures was done. An experimental study of compressive strength, modulus of elasticity and Poisson's ratio for different mix proportions were considered. Tests were conducted for clay bricks, fly ash bricks and solid blocks for mix proportions of cement mortar 1:4, 1:5 and 1:6 for masonry prisms. The type of bond used for the experiment is English bond. Dimensions of masonry prisms were 230mmx230mmx300mm. Tests were conducted on 7 and 28 days cured specimens, a total of 63 prisms. Results were verified by using ANSYS model. The experimental results proved that the prism with fly ash brick masonry achieved maximum Young's modulus and Poisson's ratio [10].

Autoclaved Aerated Concrete (AAC) production was carried out using coal residues and IOT. Bulk density and compressive strength prepared AAC was 609 kg/m^3 of 3.68 MPa respectively. This AAC mainly composed of 20% CGC (coal gangue), 40% iron ore tailings, 25% lime, 10% cement, 5% desulphurization gypsum and 0.06% aluminium powder [11].

IOT as a construction material in mortar preparation and coating was considered in the research study [12]. With IOT, mortar prepared was of three types i.e., conventional mortars, mortars with 100% replacement of fine aggregates by IOT and mortars replacing lime by IOT. Mortar characterization showed that IOT usage has increased the bulk density and also improved mechanical properties compared to the conventional mortar.

Concrete was made with silica fumes, superplasticizer and additives. Marginal materials used were lightweight aggregates with pumice, expanded perlite and rubber aggregates with water binder ratio consistent for all mixes. For varying composition of materials, strength decreased with increase in pumice, expanded perlite and rubber aggregates. Hence increase in insulation properties of concrete was observed [13].

Concrete produced with raw perlite aggregate (RPA) and varying proportion of hooked steel, wavy steel and polypropylene fibers were studied [14]. The raise in the steel fiber ratio resulted in enahncement of strength and toughness of fiber content upto 1.75%.

A detailed literature review on the utilization of iron ore mine waste and tailings and a few waste materials as marginal materials with additives to enhance the characteristics of concrete and bricks [15,16].

The main focus of the present chapter is to utilize IOT in development of bricks and concrete and to determine their basic properties as a construction material and strength properties required as per the construction industry. Due to the higher density of IOT, higher the density of brick and concrete. So, perlite is used as a density controller and used as an aggregate in bricks and concrete to produce light weight bricks and concrete blocks with high thermal resistance and good durability.

2. METHODOLOGY

The experimental study was carried out in various stages as discussed below:

2.1. Sample collection

The materials used in the present study are Iron Ore Tailings (IOT), perlite, sand, coarse aggregates and cement. Iron Ore Tailings (IOT) samples were collected from a mine tailings dam in Karnataka State, India, using random sampling method. Perlite was procured from M/s. Keltech Energies Limited (KEL), Vishwasnagar, Udupi District of

Karnataka. Locally available river sand and coarse aggregates were used. Ordinary Portland Cement (OPC) of Grade 53 (ACC) was used.

2.2. Physical and elemental analysis

2.2.1 Iron Ore Tailings (IOT)

Grain size distribution of IOT was carried out and the grain size distribution curve of the tailings is shown in Fig. 1. The particles below 4.75 mm were used in preparing the tailings bricks. The elements present in IOT are mentioned in Table 1.

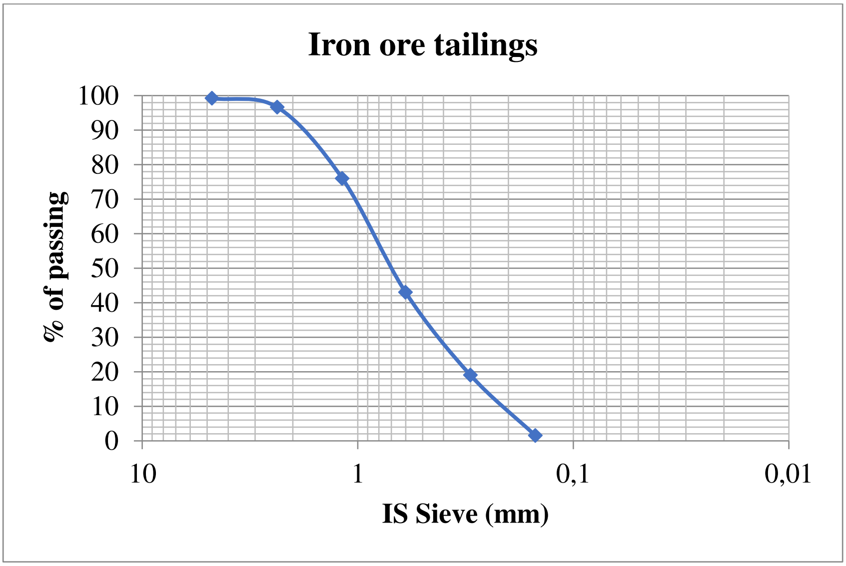

Fig. 1. The grain size distribution curve of iron ore tailings

Table 1. Elements present in iron ore tailings

Element	Weight %	Atomic %	Error %
O	34.36	59.41	7.33
Al	9.01	9.24	8.58
Si	7.36	7.25	8.20
Pb	1.24	0.17	16.21
K	0.23	0.16	66.49
Ca	0.41	0.28	52.65
Mn	0.91	0.46	33.40
Fe	46.48	23.03	2.78

2.2.2 Sand

The river sand was used for the experimental investigations. The bulk density and dry density was determined by using relative density equipment and found to be 1.86t/m3 and 1.51t/m3 respectively. The uniformity coefficient (Cu), the coefficient of curvature (Cc) and main grain size (D50) are 3.57, 1.70 and 0.89 respectively. The values of Cu and Cc proved that the sand is well graded and the D50 is used to determine the measures of gradiation. Zone I sand is used for casting of bricks.

2.2.3 Cement

Ordinary Portland Cement (OPC) of grade 53 conforming to IS 12269:1987 was used. The physical properties of cement determined are given in Table 2.

2.2.4 Coarse aggregates

Gravel of 20mm and 10mm was used in this study.

2.2.5 Perlite

Perlite is an amorphous volcanic glass formed by the hydration of obsidian and the obsidian is a naturally occurring volcanic glass formed as an extrusive igneous rock. The chemical composition of perlite is given in Table 3. Physical properties of perlite are given in Table 4 and elements present in perlite are given in Table 5.

Table 2. Physical properties of portland cement

Properties	Test Results
Normal Consistency (%)	28
Soundness, Le Chatelier's Method (mm)	1
Compressive strength, N/mm^2 for 28 days	65
Vicat Time of Setting, minutes Initial Set Final Set	 195 280

Table 3. Typical chemical composition of perlite

Chemical composition		**%**
Silicon dioxide	SiO_2	71-75
Alumina	Al_2O_3	12.5-18
Iron oxide	Fe_2O_3	0.5-1.5
Magnesium oxide	MgO	0.5-1.5
Quick lime	CaO	0.5-2.0
Caustic soda	Na_2O	2.9-4
Potassium oxide	K_2O	4-5
Hardness on Mohr's scale		3-4

Table 4. Typical physical properties of perlite

S. No	**Property**	**Value**
1	Colour	Whitish grey
2	Apparent density, kg/m^3	55
3	Specific Gravity	2.3
4	pH	6.5
5	Water absorption, % of mass	250
6	Thermal conductivity, W/mK	0.043

Table 5. Elements present in perlite

Element	**Weight %**	**Atomic %**	**Error %**
O	48.39	62.56	8.65
Na	3.76	3.38	11.61
Mg	0.79	0.67	15.60
Al	7.56	5.79	5.95
Si	33.19	24.44	4.44
K	4.22	2.23	7.70
Ca	0.78	0.40	25.80
Ti	0.55	0.24	34.00
Fe	0.76	0.28	38.29

3. MIX DESIGN AND EXPERIMENTS

3.1. Brick mix

Mix design for bricks was carried out as per IS : 3495-1976. The materials used for bricks are IOT, sand, cement and perlite. IOT and perlite are used as fine aggregates in brick mixes. Bricks of size 23.0x11.25x7.5 cm were casted for three different cement proportions (10%, 15% and 20%) and three different perlite proportions (0%, 2% and 5%). These specimens were water cured for 21 days and density and compressive strength of these specimens were tested.

3.2. Concrete mix

Concrete mix for M40 grade was designed following the IS 10262:2009. The cement content is restricted to 425 kg/m^3, with water/cement ratio of 0.40 for coarse aggregate: fine aggregate ratio of 0.64:0.36. The concrete mix is designed to achieve slump value of 25-50mm. Super plasticizer quantity of 1.0% (by weight of cement content) is added to the mix to arrive at the designated slump. Mix proportions for concrete mixes are estimated for five different compositions.

Concrete specimens of 45 numbers (100 × 100 × 100 mm) were casted to study hardened concrete properties (compressive strength) for each concrete mix. Concrete was mixed in drum mixer. Coarse aggregate, fine aggregate, IOT, perlite and cement and alccofine were added and dry mixed till uniform mix was seen for each case of mix proportion respectively. 60% of water was added and mixed again, and then the superplasticizer was mixed with remaining 40% water and then added to concrete. Once the uniform mix was obtained, fresh concrete properties were studied (slump of concrete was measured and observed to check if there was any segregation or bleeding). Concrete was loaded into moulds and sufficient compaction was given using table concrete vibrator. Specimens were de-moulded after 24 hours and immersed in water for curing for required duration. For hardened concrete, compressive strength was determined at 3, 7 and 28 days of curing age.

4. RESULTS AND DISCUSSION

Based on the experimental study, the results are analyzed and discussed in this section

4.1. Density and compressive strength of IOT bricks with perlite

Density of bricks of size 230 × 112.5 × 75 mm were determined. After water curing the IOT bricks for 21 days, these were surface dried and then weighed. On the basis of weight and volume, density of bricks was calculated.
Fig. 2(a) shows that with replacment of IOT in bricks from 30 to 60% with 10% intervals, density also increased gradually (1754.32 kg/m^3 – 1898.87 kg/m^3), later with the addition of perlite the density slightly reduced with cement replaced with 10% i.e. from 0% to 5% of perlite, density reduced from 1843.29 kg/m^3 to 1242.89 kg/m^3. Similar trend was observed in Fig. 2(b) and Fig. 2(c) for 15% and 20% cement content respectively. It can be concluded that, addition of perlite gradually decreases the density of IOT brick..

Compressive strength of bricks was determined as per IS 3495:1992 Part I, where the strength should be equal to or more than 3.5 MPa. Fig. 3 (a) shows that the compressive strength increased as the IOT percentage increased from 30 to 60% with 10% interval, but with addition of perlite, the compressive strength decreased for mix with 10% cement content. Compressive strength decreased for all IOT mixes with increase in perlite percentage from 0 to 5%. Similar trend was observed in Fig. 3(b) and Fig. 3(c) for 15% and 20% cement content respectively. It can be stated that, maximum of 50% IOT mix with 20% cement and 5% perlite gives better compressive strength compared to control mix. Though the perlite addition reduces compressive strength, it lowers the density and thermal conductivity, which are advantageous.

The better compressive strength is obtained at 5% addition of perlite and it was concluded that 8% mass addition of expanded perlite is required to keep acceptable compressive strength. It is concluded that better compressive strength is obtained at less addition of perlite [14].

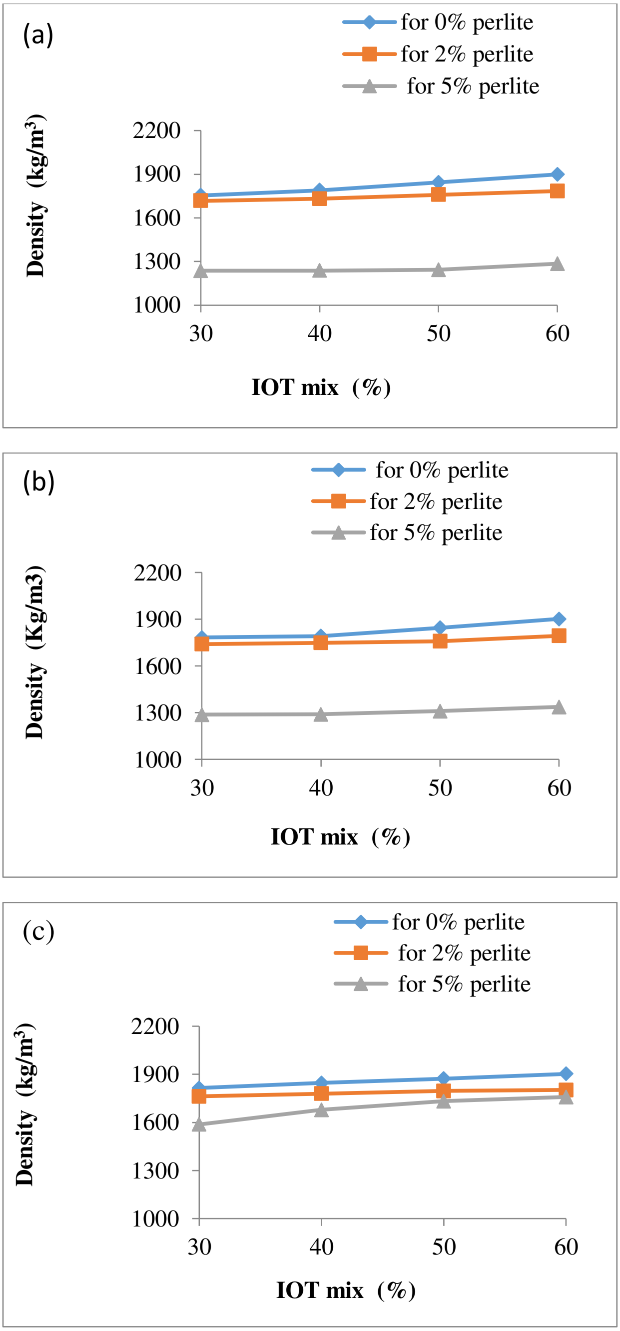

Fig. 2. Density for bricks with 10%, 15% & 20% cement for different IOT mix percentage

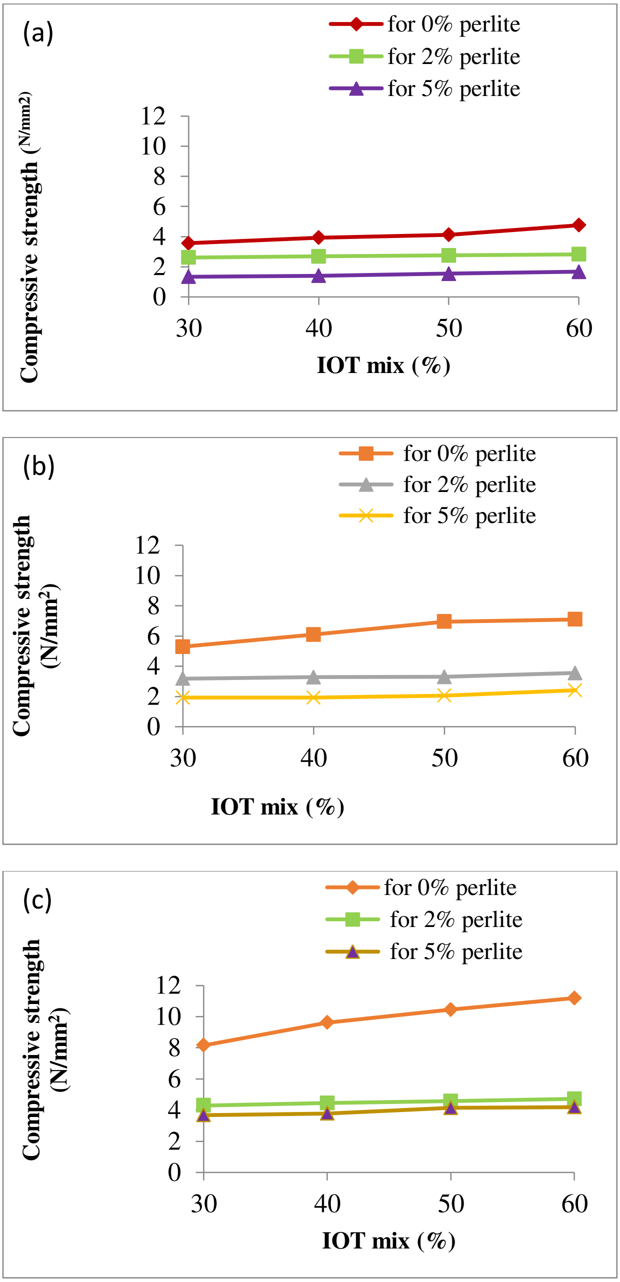

Fig. 3. Compressive strength of bricks with 10%, 15% & 20% cement for different IOT mix percentage

4.2. Workability, density and compressive strength of IOT-alccofine concrete with perlite

Experimental investigations was conducted using IOT and alccofine in concrete by Gayana and Ram Chandar [17], with IOT replaced as sand and alccofine as binder replacement by 10%. In the present study, this mix is considered and perlite is added to the same and the properties were determined.

The slump of mix with IOT-alccofine concrete is 30mm and with addition of perlite the slump value reduced with increase in perlite content as shown in Fig. 4.

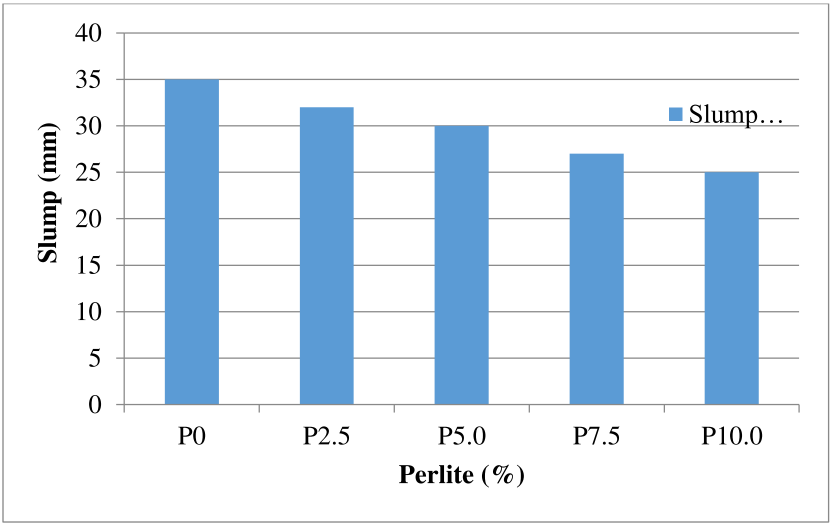

Fig. 4. Workability of IOT-alccofine-perlite concrete

Density of control mix of IOT-alccofine concrete is 2546.67 Kg/m^{3,} with addition of perlite by 2.5% to 10% with 2.5% interval was determined and the same is shown in Fig. 5. It can be observed that with addition of perlite, the density of concrete cubes decreased making it a light weight concrete.

Compressive strength of IOT-alccofine concrete is 57.33 MPa for 28 days cured concrete specimen. Perlite was added to this mix in varying percentage by 2.5% to 10% with 2.5% interval and the strength was determined for 3, 7 and 28 days cured specimens. The trend can be observed in Fig. 6 that, with addition of perlite, strength of concrete specimens decreased gradually. But, the strength obtained was as per the requirements of Indian standards for M40 grade concrete. The optimum percentage of perlite is 2.5% and IOT is 30% and alccofine is 10% at which maximum strength was observed.

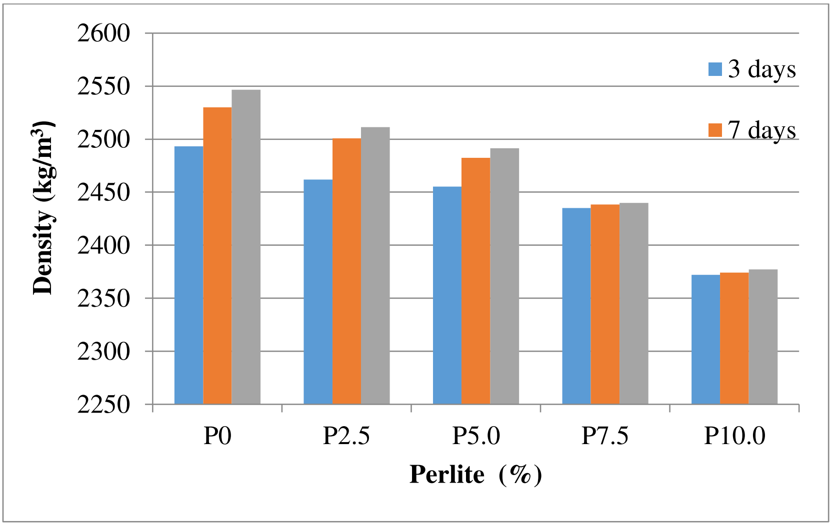

Fig. 5. Density of IOT-alccofine-perlite concrete

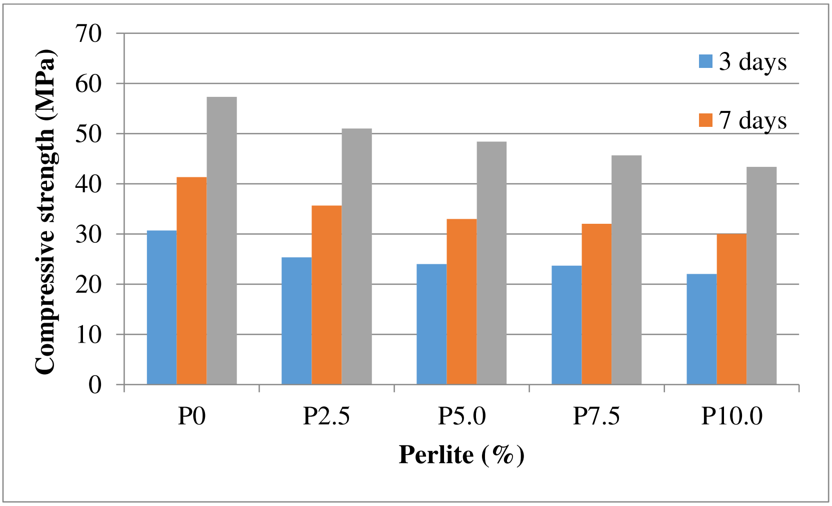

Fig. 6. Compressive strength of IOT-alccofine-perlite concrete

5. CONCLUSIONS

Based on the experimental study on bricks and concrete mixes with IOT and perlite, the following conclusion are drawn:

Material Properties: Physical properties of OPC 53 grade and alccofine was used as binder material and river sand, iron ore tailings (IOT), crushed granite, and perlite (P) were used as aggregates and these materials conform to the IS codes and are within the limits. The specific gravity of IOT is 3.31, is high compared to river sand and has water absorption of 2.29. IOT has high surface area due to which it absorbs high water content in concrete.

Chemical composition of the materials i.e., IOTs were determined using elemental analysis by Scanning Electron Microscope (SEM) and it was observed that, the materials consists of major elements viz., high percentage of Silicon dioxide (SiO_2), Iron oxide (Fe_2O_3), Aluminium oxide (Al_2O_3), Calcium oxide (CaO).

Bricks: The density of bricks with IOT and perlite was between from 1754.32 Kg/m^3 to 1902.48 Kg/m^3 for IOT replacement from 30% to 60% respectively. The increase is density is due to the high specific gravity and surface area of IOT and the same has resulted from the experimental results. The density of brick is reduced by the addition of perlite. When perlite percentage increased from 0 to 5%, the density decreased from 1902.48 kg/m3 to 1732.43 kg/m^3 for mix with 50% IOT and 5% perlite. Compressive strength of bricks enhanced with increase in percentage of IOT and cement. The compressive strength reduced by increasing the perlite content. To obtain minimum 3.5 N/mm2 compressive strength and to satisfy the IS specifications, brick requires 50% of IOT, 20% cement and 5% of perlite.

Concrete: In IOT-alccofine-perlite concrete, the slump value of concrete reduced with addition of perlite content. The density of concrete decreased due to the presence of perlite with reference to the control mix. Compressive strength reduced with increase in perlite quantity from 2.5% to 10% with 2.5% intervals with reference to control concrete. Strength decreased by 11.04%, 15.62%, 20.33% and 24.33% for 2.5%, 5%, 7.5% and 10% perlite content for 28 days cured specimens. Compressive strength of the control mix is 57 MPa, whereas with addition of perlite, it decreased to 51 MPa at optimum percentage of perlite of 2.5%. But the strength obtained satisfies as per IS standards for M40 grade concrete.

Nomenclature

IOT	:	Iron Ore Tailings
MPa	:	Mega Pascal
°C	:	Degree Celcius
gm/cc	:	Gram per cubic centimetre
MSW	:	Iron Mine Spoil Waste
CSEB	:	Compressed Stabilised Earth Block
AAC	:	Autoclaved Aerated Concrete
CGC	:	Coal gangue
RAP	:	Raw Perlite Aggregate
Kg/m^3	:	Kilogram per cubic metre
mm	:	Milli metre
t/m^3	:	Tonnes per metric cube
Cu	:	Uniformity coefficient
Cc	:	Coefficient of curvature
D50	:	Grain size
OPC	:	Ordinary Portland Cement
IS	:	Indian Standards
N/mm^2	:	Newton per square millimetre
SiO_2	:	Silicon dioxide
Al2O3	:	Aluminium oxide
Fe2O3	:	Iron Oxide
MgO	:	Magnesium oxide
CaO	:	Calcium oxide
Na2O	:	Sodium oxide
K2O	:	Potassium oxide
W/mK	:	Watts per metre Kelvin
O	:	Oxygen
Na	:	Sodium

Mg	:	Magnesium
Al	:	Aluminium
Si	:	Silicon
K	:	Potassium
Ca	:	Calcium
Ti	:	Titanium
Fe	:	Iron

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