INVESTIGATION AND ASSESSMENT OF QUALITY OF BRICKS PREPARED USING IRON ORE WASTE

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

By

SHREEKANT REVACHAND LAMANI

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA
SURATHKAL, MANGALORE – 575 025
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DECLARATION

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis entitled **"Investigation and Assessment of Quality of Bricks Prepared Using Iron ore Waste"** which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Mining Engineering** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

Shreekant Revachand Lamani
(Register No.: **123003MN12P02)**
Department of Mining Engineering

Place: NITK–Surathkal
Date: 09-02-2017

CERTIFICATE

This is to certify that the Research Thesis entitled "**Investigation and Assessment of Quality of Bricks Prepared Using Iron ore Waste**" submitted by **Shreekant Revachand Lamani** (Register Number: **123003MN12P02**) as the record of the research work carried out by him, is *accepted as the Research Thesis submission* in partial fulfillment of the requirements for the award of degree of **Doctor of Philosophy**.

Research Guides

(Name and Signature with Date and Seal)

Dr. Harsha Vardhan Dr. M. Aruna

Chairman – DRPC

(Signature with Date and Seal)

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EXECUTIVE SUMMARY

Mining is the backbone of many countries economy. Iron ore mining plays a significant role in production of steel and other metals, but at the same time generates massive waste which pollutes the environment and brings other issues related to its storage and handling. Hence there is a need to develop a comprehensive plan for utilisation, storage of iron ore waste fines from the point of view of saving resources and sustainable development. Iron ore waste fine has low percentage of Fe_2O_3, hence it is discarded. Iron ore waste is dumped at relevant place as per the approved mining plan. It occupies large area within the lease boundary, degrades surrounding land and also deteriorates the environment.

In general, any building materials are directly or indirectly prepared from the earth's crust. The basic composition of building materials is nearly same as the composition of earth (i.e. silica, aluminum oxide, iron etc.). In the recent years, there has been a significant demand for building materials in India as well as all over the world. Therefore, it is imperative to use mining and mineral wastes in the production of bricks, paving blocks and other value added products which are used in the construction industry. Since the need for building materials is growing at an alarming rate, therefore in order to meet the demand for new buildings, new ways and techniques must be evolved for brick making. Manufacturing of building materials like brick, cement, steel, aggregates, etc. which are consumed in bulk quantities, puts great pressure on natural resources and are highly energy demanding. Therefore, the use of alternative material for brick manufacturing should be encouraged. Hence, there is a scope for utilizing mine wastes for the manufacturing of building material and other products. Mine wastes and tailing can be converted into bricks/paving blocks, which can meet the demand of brick in metropolitan cities for the next 30 years or even more. Similarly, utilizing the iron-ore waste tailings can fulfill the requirements of bricks for Karnataka State for many decades. Thus, there is great potential for utilizing mine wastes to manufacture building materials and products.

The crux of this investigation was the possibility of making bricks by mixing iron ore waste fines from iron ore mines with other additives like cement and fly ash. In this investigation, the iron ore waste percentage (by mass) was varied from 65 to 90, whereas that of cement was varied from 0 to 30. The cement percentage was restricted to a maximum of 30 %, based on the study carried out by various other investigators. Similarly the fly ash percentage by mass was varied from 0 to 30. Iron ore waste fines were collected from the run-off of dumps from a large opencast mine of M/S. Sandur Manganese & Iron Ore Limited located in the state of Karnataka. A total of nine iron ore waste fine samples were collected from nine different locations in consultation with the mine management. However, samples collected from only six locations were considered for this study based on the chemical composition, especially the Fe_2O_3. Three samples where in Fe_2O_3 was more than 30 % was not considered as waste as they could be upgraded to iron ore in near future. Fly ash for this investigation was collected from Udupi Power Corporation Ltd.

It was found that around 90 % of the collected iron ore waste fines were below 600 μ size. Hence, iron ore waste fines are directly suitable for preparation of non-fired bricks without going for any crushing, grinding or screening processes. The investigation revealed that cement can be readily used as an additive/binding material for preparing non-fired bricks from iron ore waste fines found in iron ore mines. These bricks comply with IS Standards IS 13757:1993 of class designation 3.5, which can be used in the construction of simple temporary and cheap structures which are not exposed to heavy rains. Bricks with 9 % cement content as an additive in brick making along with fly ash and iron ore waste fines will meet the desired compressive strength as per BIS guidelines of 3.5 MPa with 28 days of curing period. With 10 % cement content in the brick with varying percentage of fly ash and iron ore waste fines, the bricks with several combinations attain the desired strength as per BIS standards much below 28 days (7 days, 14 days and 21 days) and therefore can be used as a construction material even without 28 days of curing the details of which are presented in this thesis. All the bricks prepared with 9 % cement content as binding material and with curing of 7 days and above meet the BIS standards of water absorption. Investigation has revealed that bricks prepared with below 9 % cement as binding material will deform once removed from the mould and will have very low compressive strength of the order of 0.55 to 0.67 MPa with 28 days of curing. Fly ash from thermal power plants should also be used along with cement and iron ore waste fines in brick making process. The fine fly ash particles improves the concrete pore structure thereby stimulating early strength development and also increases the compressive strength of bricks. Further addition of fly ash in the brick, makes the brick lighter. It was found that there is a significant reduction in weight of the bricks of around 0.5 kg by using fly ash compared to that of bricks prepared without fly ash. Hence, it is recommended to use fly ash in the process of brick making using cement and iron ore waste fines. Further, use of fly ash in making brick is environmental friendly too. It was found that the bricks prepared with 30 % cement, 25 % cement, 20 % cement, 15 % cement and 10 % cement costs ₹ 10, ₹ 9.20, ₹ 8.70, ₹ 7.80 and ₹ 7.20 per brick (excluding profit), respectively, which is substantially below the cost of fired compressed bricks available in the market (costing ₹ 15 per brick). As the cost figures arrived in this research work are based on the cost computation of prepared bricks on laboratory scale, it is anticipated that the cost figures may reduce further when the brick preparation is done on industrial scale. A number of regression equations have been developed for predicting compressive strength and percentage of water absorption of prepared bricks with different days of curing. These equations can be readily used to find out the compressive strength and water absorption of bricks with acceptable level of accuracy. Results on the investigation of the impact of chemical composition of bricks on its compressive strength has revealed that there is no proper relationship of it with total percentages of SiO_2 and Al_2O_3 present in a brick. With increase in total percentage of Fe_2O_3 present in a brick, its compressive strength was found to decrease gradually. Hence, it is suggested to prepare non fired bricks from iron ore waste fines containing low percentage of Fe_2O_3 which is also desirable from the point of view of mineral conservation. However, further work needs to be carried out in this direction to confirm the above mentioned results.

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CHAPTER -1

1.0 INTRODUCTION

1.1 GENERAL

India has large reserves of metal-bearing ore and as on 2012, it stands fifth position in the world with regard to iron-ore reserves. The production of iron ore at about 152.43 million tonnes in 2013-14 registered an increase of 11.58 % over the previous year 2012-13. About 39 % of the total production was shared by Public Sector Companies and 61 % by private sector. During this period (2013-14), Odisha was the leading producer of iron ore accounting for 50 % of the total production followed by Chhattisgarh (20 %), Jharkhand (15 %), Karnataka (12 %) and remaining (3 %) production was reported from Andhra Pradesh, Madhya Pradesh, Maharashtra and Rajasthan (Annual Report 2014-15, Ministry of Mines, Govt. of India). The major production of iron ore in Karnataka is from the districts of Bellary, Chitradurga and Tumkur.

The general perception about mining is that, it is hazardous industry causing significant damage to the environment in different ways. To make mining activities more environment-friendly, economically feasible, and socially acceptable, it is important to use practices that are more sustainable in handling the wastes generated. The voluminous amount of waste generated from the mining and processing activities is one of the major concerns for the mining industries and the community at large. The availability of iron ores in Karnataka particularly Hospet sector has attracted significant investment in the mining sector and it has resulted in several operating iron ore mines. The high extent of mining activities in this sector has brought about significant volumes of mine wastes which need to be handled by the mining firms. Some of these wastes generated are iron ore waste, iron ore tailings, waste rocks, overburden etc. The disposal of these wastes needs to meet local legislations and expectations of the community around.

1.2 UTILIZATION OF MINE WASTE / TAILINGS

Though India is one of the important iron ore producer and exporter in the World (Aruna, 2012), still, approximately 10-15 % of the iron ore mined in India is unutilized and is discarded as waste / tailing. This is mainly due to lack of cost effective technology in extracting low grade ores (Rudramuniyappa, 1997). Some of the waste / tailings having diameter less than 150 µm are called ultra-fines or slimes and are not considered to be useful at all and hence are discarded. Approximately, 10-18 million tons of such ore is lost as tailings in India (Das, 2000; Mohanty et al. 2010). Proper 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. Therefore, comprehensive utilization of waste/tailings is important in, improving surroundings and for sustainable development.

In recent years, there has been a significant demand for building materials in India as well as all over the World. Therefore, it is imperative to use mining and mineral wastes in the production of bricks, paving blocks and other value added products, which are used in the construction industry (Chakravarthi et al. 2007, Muduli et al. 2010). Since the need for building materials is growing at an alarming rate therefore in order to meet the demand for new buildings, new ways and techniques must be evolved. In order to fulfill the demand of construction industry, manufacturing of building materials like brick, paving blocks etc. should be encouraged. Hence, there is a large scope for utilizing mine wastes for the manufacturing of building material and products. Mine wastes and tailing can be converted into bricks / paving blocks, which can meet the demand of brick in metropolitan cities for the next 30 years or even more. Similarly, utilizing the iron-ore waste / tailings can fulfill the requirements of bricks for Karnataka State for many decades (Chakravarthi et al. 2007). Thus, there is great potential for utilizing mine wastes in the manufacturing of building materials and products.

1.3 DEFINITION OF THE PROBLEM

The concept of brick making using iron ore waste fines (henceforth in this thesis iron ore waste fines will be denoted as "IOW") or any other mine waste is not new. Several studies have been carried out in the past by various investigators throughout the world in attempting brick making using iron ore waste / mine waste. A simple search on the internet using any of the search engines will indicate the quantum of work carried out in this area. Hence, it may be argued among the scientific community regarding the novelty of this work. Though there has been significant amount of work carried out in the area of brick making using iron ore waste, the results of limited number of studies have only been utilized, particularly in India on industrial scale using iron ore waste in brick making. Further, very few studies seem to have

studied the effect of some of the constituents of iron ore waste on the compressive strength of bricks. Added to this, a mathematical model for predicting the compressive strength and water absorption of bricks for bricks made using different proportions of iron ore waste, cement and fly ash has not been investigated in depth to the knowledge of the scholar. In view of the above, it was felt that such an investigation would be actually useful to the mining industry. The industry may be benefitted by setting up brick making plant for their own internal use as well as for commercial purpose. Further, it is going to help in reducing the problems due to storage and handling of the mine waste at mine sites.

1.4 CONTENTS OF THE THESIS

The nine chapters in this thesis are presented in a logical order starting with Chapter 1 that provides the general introduction to mine waste/tailings and its effective utilization in preparation of bricks. Chapter 2 discusses the review of literature regarding the types of bricks and utilization of mine waste/tailings in preparation of value added products for construction industry as well as other engineering applications. Chapter 3 describes the objectives and scope of the present research work. The equipments and instruments which were used for the laboratory experiments are described and presented in Chapter 4. Chapter 5 describes the methodology involved in field investigation and laboratory investigation. The methodology involved in determination of various parameters of laboratory investigation as well as preparation of bricks are also discussed in this chapter. The experimental results and their analysis are summarized in tables and figures in Chapter 6 of results and discussion. Chapter 7 explains development of mathematical model for assessment of quality of bricks and its validation. The impact of chemical composition of bricks on its compressive strength is presented in Chapter 8. Finally, Conclusions on the present research work and scope for further work are included in Chapter 9.

CHAPTER – 2

2.0 LITERATURE REVIEW

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 varies. 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 divided in to two classes. 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 water absorption is less than 10 %. These types of bricks are used for heavy engineering works, like bridge structure, industrial foundation 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 vary 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 perforated building 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, 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 sand and lime 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 are manufactured from clay, fire clay or shale or combination of these materials. As per BIS (IS 4885:1988) the size of these bricks should be between 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 these bricks are its material 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 are operated at high temperatures (Kulkarni, 1999).

Table 2.1 gives the detailed classification of heavy duty and commercial burnt clay bricks based on compressive strength (IS 2180:1988, IS 1077:1992).

Table 2.1: Classification of Bricks Based on Compressive Strength

Type of bricks	Average compressive strength not less than (MPa)	Class designation
Heavy duty bricks	45.00	45.00
	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

2.2 CLASSIFICATION OF 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 bricks 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 - 35ºC and hot air temperature below 100ºC, 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 - 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.

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. It was also reported that, 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 was 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, lead 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 de-bonding 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 is 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 of 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 the 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, showed that 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 mixes 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 was 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).

Innovative methodologies 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 to be of 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 was carried out on utilization of Mn - Fe solid wastes which is 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 was carried out by Yongliang et al. (2013), wherein 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 1200ºC 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 cementitious material. This cementitious 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 cementitious property of raw tailings. The results show 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 was 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 with 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 was 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 could 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 that the linear regression models can be used to predict relationships of IOT-OPC concrete.

Yellishetty et al. (2008) studied the use of iron ore mine tailings from Goa in India as an aggregate in concrete. They obtained the iron ore mine wastes from four different types of mine waste dumps in different companies in Goa and mixed them together. They made two types of concrete, one with the mine aggregate and the other with normal granite quarry aggregate in concrete and compared the properties of the two different concrete with different aggregate. The composition of the concrete was in different proportions using mine aggregate (12.5 mm – 20 mm in size), sand and cement as the binder. They concluded that the aggregate component of the mine wastes conforms to the Indian Standard Specifications for quality standards of aggregates. Their work is also an improvement for making concrete by adding some mine wastes to partially replace the coarse aggregate part. The use of mine wastes for 100 % replacement for both fine and coarse aggregates will avoid the use of natural sand and natural granite quarry completely.

Bhatty & Reidt (1989), made pellets and slabs from sludge ash and used as lightweight aggregates in lightweight concretes. A concrete mixture was made with the pellets and slabs as aggregates, cement and sand in different proportions. They found out that the moderate strength concretes produced from the pellets have better strength characteristics than those made of slabs and other commercial aggregates mainly because of their shape (spherical), uniformity of size and low moisture absorptions.

A study was conducted into the suitability of using iron ore mine tailings from Goa in India as aggregates in making concrete and building material (Karpe, 2011). 40% by weight of the mine wastes with size of 12.5 – 20 mm was used as aggregate in the concrete mix. The concrete mixture contained mine wastes as coarse aggregates, siliceous sand as fine aggregates and portable water with neutral pH and ordinary Portland cement. Based on the mixture, concrete blocks were made and cured for 28 days. Another set of concrete blocks were made with granite as the coarse aggregate instead of the mine wastes. The strength of the concrete with mine wastes aggregates was 225 kg/cm^2 and that of granite aggregate was 200 kg/cm^2. The ratio used was 1: 2: 4 cement, sand and aggregate respectively. They concluded that the compressive strength of concrete made of mine wastes as aggregate was more than that of the concrete made of granite as aggregate and the mine wastes aggregates of the concrete conforms to Indian Specification Standards.

2.3 UTILIZATION OF MINE / MINERAL 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, reduced. Whereas, Reddy (2004) says that there is a large scope for research and development 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 principal 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 IOT in building construction to examine the compressive strength of the IOT concrete for construction work was investigated. Analysis made using Minitab software for the statistical analysis were 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 a 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).

IOT can also be used as replacement to fine aggregates in cement concrete pavements. The properties of IOT (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) which 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).

Chen et al. (2011) investigated the possibility of making construction bricks by using hematite tailings from Western Hubei province of China. They mixed the hematite tailings with clay and class F fly ash in different proportions. The process included mixing, forming, drying and firing. They found out that with hematite tailings of 84 %, forming water content 12.5 – 15 %, forming pressure 20 – 25 MPa, firing temperature 980ºC – 1030ºC for 2 hours, the bricks produced had a water absorption of 16.54 – 17.93 % and mechanical strength of 20 – 25 MPa and these properties of the newly produced bricks conformed to the Chinese Fired Common bricks standard GB / T5101 – 2003 (State General Administration of China for Quality and Quarantine, 2003).

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 was 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 of 0.15 was 13.5 MPa and 14.7 MPa respectively at moulding pressure of 25 MPa with 7 days curing. Similarly, 17.4 MPa and 21.3 MPa at moulding pressure 30 MPa was achieved 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). For the study copper tailings, river sand and limestone were used 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 show that the copper tailings when used as main raw material by adding sand increase the content of SiO_2 and hydrated calcium silicate, which gives high strength to bricks and also reduce its weight. The content of copper tailings in the brick does not exceed 50 % and brick is autoclaved at 180ºC for 7-9 hours.

Ahmari and Zhang (2012), investigated the feasibility of utilising copper mine tailings from Mission Mine operations of ASARCO LLC in Tucson, Arizona in the United States of America for the production of eco-friendly bricks based on the geopolymerization technology. The geopolymerization is the reaction undergone by aluminosilicate materials in a highly concentrated alkali hydroxide or silicate solution, forming very stable material called geopolymer having amorphous polymeric structures with interconnected Si-O-Al-O-Si bonds. In their process they mixed the copper mine tailings with sodium hydroxide (NaOH) solution and formed the bricks by compressing the mixture within a mould under a specified pressure and curing the bricks at slightly elevated temperatures. Their method did not follow the conventional one by using clay and shale and firing at high kiln temperatures. They checked the properties of their geopolymer bricks through water absorption, unconfined compressive strength and abrasion resistance. It was observed that the compressive strength of the geopolymer bricks varies from 3.69 MPa to 33.7 MPa at 15 M NaOH concentrations with curing temperature of 90ºC for 7 curing days.

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±1ºC 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 hours 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

Dean et al. (1996) used the gold mill tailings in addition to fly ash, Portland cement and water to manufacture concrete blocks of size 10.16 cm × 20.32 cm and achieved the average compressive strength of 18.34 MPa. This is almost 40 % higher than the American Society for Testing and Materials (ASTM) requirements for load bearing block (i.e. 13.10 MPa). At the same time the bricks made with this material had compressive strength of 28.22 MPa which is 17 % higher than that ASTM requirement.

Roy et al. (2007) carried out an experimental study on gold mill tailings in making bricks – a feasibility study of Kolar Gold Fields. The bricks were prepared with the mill tailings having cement as an additive in 5, 10, 15, 20 and 25 % with curing duration of 3, 7, 14 and 28 days. These were tested and results indicated that with 20 % cement for 14 days curing are most suitable with the compressive strength 36 kg/cm^2 (3.43 MPa), which just meets the criteria of assessment of bricks with minimum compressive strength 3.43 MPa (Jha, 1992). However, in all the cases of mixture it was observed that the water absorption was less than 20 %, irrespective of the firing temperature. Hence, it meets the criteria of assessment of quality of bricks which should be less than 20 % after 24 hours 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 (>= 70 % of mill tailings) cause deformation problem with black cotton soil and cracks after firing with red soil for >= 55 % of mill tailing. It was also observed that for lower percentage of mill tailings content, the linear shrinkage of bricks was more than 3 %, and hence it did not satisfy the criteria. Results of cost analysis study reveals that the soil tailing bricks are economical when compared to cement tailing bricks.

Yonggang et al. (2011) made fired bricks using gold mill tailings and clay, following the sequence of pretreatment, mixing, ageing, moulding, drying, sintering and performance testing in making of bricks. It was found that the compressive strength can reach the Standard MU10 (Fired Common Brick) when 70 % to 90 % fine tailing was fired at 1000ºC with 60 minutes holding time.

Celik et al. (2006) considered gold mine tailings as one application as an additive in the manufacture of Portland cement. The results indicated that gold tailings between 5 to15 % as an additive could be feasible in Portland cement production if the gold tailings used in the cement are blended with silica fume and C type fly ash to attain the desired values of compressive strength (60 N/mm^2). The chemical composition and some physical properties of the gold tailings and other materials were also reported by Celik et al., 2006.

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 23ºC. 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 1125ºC were found to be utilized for making acid resistance bricks. Batch S2 (50 % KFQR, 20 % GBFQR and 30 % GBFS), fired at 1125ºC 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

Turgut (2010) carried out an investigation 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 were kept in a mold for 4 hours 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 105ºC for 24 hours. 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.

2.4 Utilization 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. These mixtures were used 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±2ºC 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 of casting/curing, which satisfied IS Standards (IS 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 (IS 13757:1993). Because as per the IS Standards, the water absorption should not be more than 20 % (by weight).

Freidin and Erell (1995) studied on manufacturing of bricks by using coal fly ash, slag and water-glass cured in the open air for 28 days at 20 – 23ºC. 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 consisting 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 – 20.0 MPa.

Cicek and Tanrıverdi (2007) used light weight lime based steam autoclaved fly ash bricks using fly ash, sand and hydrated lime for manufacturing bricks. 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 hours autoclaving time and 1.5 MPa autoclaving pressure. Similarly, the Physico-mechanical properties reported were of the compressive strength of 10.25 MPa with water absorption at 40.5%, volume weight at 1.14 g/cm^3 and thermal conductivity of 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.

Experimental study was 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 ratios of 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 most of the bricks belonged to Class 3.5 and 5 in respect of compressive strength (IS 13759:1993). But the bricks prepared L & FA in ratio 40:60 satisfy the criterion of Class 3.5 in respect of both compressive strength and water absorption.

An experimental study was conducted on cellular light –weight concrete blocks as a replacement of clay bricks. The study showed that the use of fly ash in foamed concrete greatly improves its properties and cellular light weight concrete blocks give 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. The prepared bricks were of size 225 mm x 10 mm x 5 mm and cured for 21 days. The water absorption and compressive strength of FAL-G bricks were of 15% and 22.68 N/mm^2

respectively. The experiments were also carried out on FAL-G brick prism masonry using Rap-Trap method and at 14 days for which the compressive strength observed was 88.05 kg/cm^2 for cement mortar (1:6) and 88.83 kg/cm^2 for fly ash mortar (1:6). It was also reported that the compressive strength could 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 Rap-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 tons per annum, the utilization rate is 73.13 million tons per annum only. The un-utilized fly ash is about 922.95 million tons 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 % is also highlighted.

Banu et al. (2013) carried out study in making bricks by adding fly ash-sand-lime and gypsum. 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 of 1.81 gm/cm^3, initial rate of absorption at 14.84 %, absorption capacity at 11.58 %, open pore volume of 9.23 cm^3 and impervious pore volume of 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. (2015) on compressive strength of fly ash brick with addition of lime, gypsum and quarry dust 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 in the range of 15 % to 50 %, gypsum at 2 %, lime in the range of 5 % to 30 % and quarry dust in the range of 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, 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 fly ash at 15 %, lime at 30 %, gypsum at 2 % and quarry dust at 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 hours and 10 hours, 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 of 13.1 MPa and 56.3 MPa respectively can be obtained by using -40 micro meter fly ash as body and by firing at 950ºC. It was also observed that most of the samples had low weight and low shrinkage (not more than 3 % as compared with clay brick).

Ferone et al. (2007) used weathered coal fly ash from ENEL SPA Power plant in Brindisi of Southern Italy to produced bricks based on the geo-polymerization technology. Sodium silicate solution and sodium hydroxide solution was used as the alkali activator. Different specimens were prepared in different proportions using mixtures of fly ash, sodium silicate solution and sodium hydroxide solution. The specimens were moulded in cylindrical polyethylene moulds and were cured in different durations and at different temperatures. They observed that at 60ºC of curing temperature for seven days, the unconfined compressive strength (UCS) of the bricks increases. In their study, it was proved that instead of mixing both the sodium silicate and the sodium hydroxide solutions as the alkali activator, sodium silicate solution alone could also be used which may provide the same strength and also reduce cost by using only one activator instead of mixing two activators.

Arioz et al. (2010) used the geo-polymer technology on fly ash to produce bricks that met specific requirements. It was reported that the properties of a geo-polymer paste depend on the type or source of material used. Since a number of studies have focused on fly ash for many years, other waste materials that contain silica and alumina such as iron ore mine wastes should also be investigated to bring more alternatives.

2.5 Closure

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.

CHAPTER – 3

3.0 ORIGIN, OBJECTIVES, JUSTIFICATION AND SCOPE OF THE RESEARCH WORK

3.1 Origin of Present Research Work

Department of Mining Engineering, N.I.T.K., Surathkal is well known to all mining industries in and around Karnataka. As a part of curricular activity, it is a regular practice of the Department to conduct short mine visits to the neighbouring mines. Also, many of the mining companies take technical support of the department in the form of Research and Consultancy services. During the course of visit to several iron ore mines, the department came to know about the problem of storage of mine wastes from the mine officials as well as mine owners. Based on their advice, this problem was taken up as a research activity.

Further, detailed literature review in the area indicated that there is limited work carried out by various investigators for developing a mathematical model to assess the quality of bricks prepared using iron ore waste. Also investigation on the strength of bricks with respect to the presence of Al_2O_3, SiO2 and Fe_2O_3 has not been studied in detail to the knowledge of the scholar.

3.2 Objectives

The research work was taken up with the following specific objectives:

a. Investigation of the quality of bricks prepared using iron ore waste-fines and its comparison with those of standard bricks used in the construction industry.
b. Investigating the impact of the constituents of prepared bricks (SiO_2, Al_2O_3 and Fe_2O_3) on its compressive strength.
c. Development of a mathematical model / regression model for prediction of compressive strength and water absorption in bricks made using iron ore waste.

3.3 Justification

Using the developed mathematical model reported in this thesis, one can easily assess the quality of iron ore waste bricks by substituting the mass percentage of iron ore waste, cement and fly ash. It is thus hoped that results of this investigation will serve mine owners in utilisation of iron ore waste. Further, the construction industry will also be benefitted as there is acute scarcity of river sand. Also, the bricks suggested for use in this thesis are non-fired bricks which are known to be eco-friendly.

3.4 Scope of the Present Investigation

It is well known fact among the mining community that voluminous amount of waste is generated during the process of iron ore mining. This in turn results in several environmental pollution like, land degradation due to its storage, air pollution and run-off from the dump causing water pollution etc. Hence there is a need to develop some technology for utilisation of these voluminous waste for some useful purpose. Brick making for the construction industry can be one option for making use of these iron ore waste.

Hospet Sector in the Bellary District of Karnataka State, India is known for its extensive iron ore mines, iron ore production and hence iron ore waste generation. This district is only around 350 to 400 km from NITK- Surathkal. Hence, it was felt that iron ore waste can be collected from this sector for the present investigation. In this connection M/S Sandur Manganese and Iron Ore Company Pvt. Ltd. (SMIORE) having a lease area of around 5000 Ha in total was contacted and they readily agreed for providing necessary assistance for field investigation.

The following are the scope of the present investigation:

i. Detailed literature review in the specified area of the research work.
ii. Study of iron ore waste samples collected from the field to determine its chemical composition.
iii. Characterization of iron ore waste collected from the field to study its morphology and chemical composition by using SEM technique and comparing the results with those obtained by conventional chemical methods.
iv. Preparation of bricks as per IS standards using iron ore waste, cement and fly ash in different proportions.
v. Testing of prepared bricks as per IS standards for different curing period and its comparison.

vi. Studying the impact of composition of iron ore waste (IOW) namely Al_2O_3, SiO_2 and Fe_2O_3 on compressive strength of bricks.

vii. Developing a mathematical / regression model for predicting the compressive strength and water absorption of bricks.

viii. Testing of the developed mathematical / regression model.

ix. To carry out cost analysis of the prepared bricks and compare it with the cost of the commercially available bricks.

CHAPTER – 4

4.0 EQUIPMENTS / INSTRUMENTATION

4.1 GLOBAL POSITIONING SYSTEM

The hand held Global Positioning System (GPS) of Garmin make, Model 76CSx (Fig. 4.1) was used for the purpose of identifying coordinates of the sample location (nine locations). These co-ordinates were used in identifying the same location for subsequent sample collection.

Fig. 4.1 Hand Held GPS System – Garmin-76CSx

4.2 HOT AIR OVEN

RoTek make RHO-18 hot air oven (1200 watt) was used in this thesis for removing the moisture content of the samples (Fig. 4.2). The oven had a capacity of 95 litres and had three shelves. The temperature range provided in the oven is +50 – 200 ˚C with an accuracy of ±1˚C.

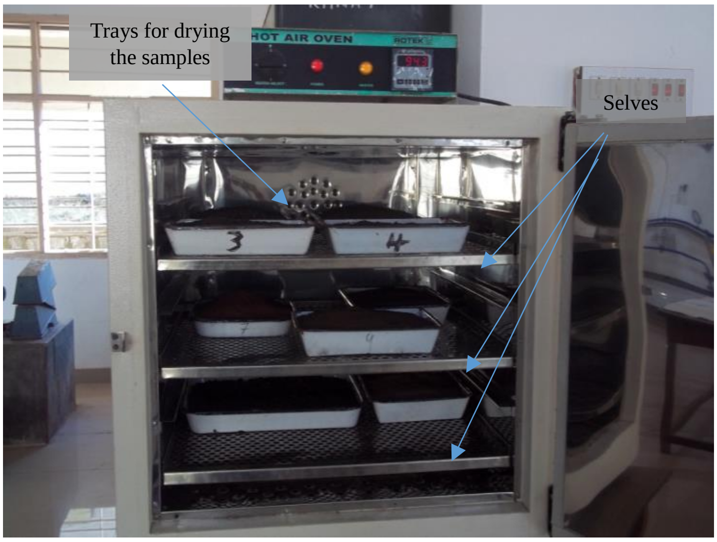


Fig. 4.2 Hot Air Oven

4.3 QUADRANT DIVIDER

Sampling is a process of taking representative sample from a given large quantity of sample and is done by various techniques. The coning and quartering technique was adopted to carry out the sampling process in this work (Fig. 4.3). Coning & quartering technique is basically a sample reduction technique as its successive iterations reduces the sample to half of its previous value (quantity) each time. This method is convenient for any quantity of material. Steps involved in this method are making pile of material (conical in shape), settled at its natural angle of repose. The cone has to be radially symmetrical. Then with the help of a spatula, it is flattened into a circular disc and subsequently quartered using the Quadrant Divider. Quarter of opposite quadrants is taken and remaining material is discarded. This process is repeated till the desired sample quantity is achieved.

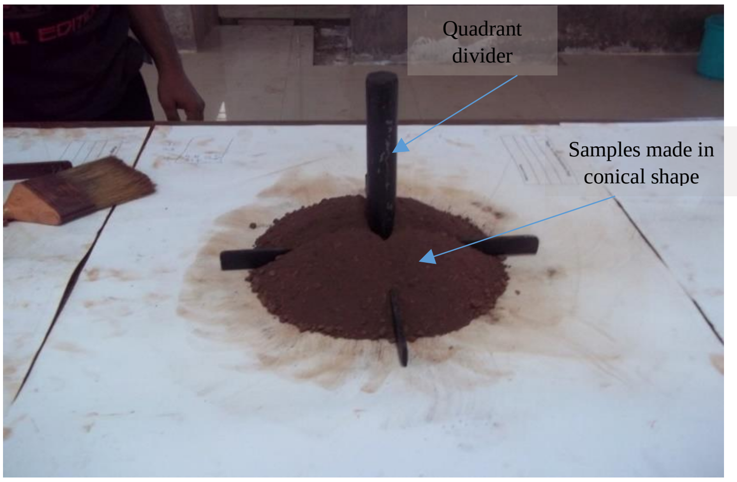


Fig. 4.3 Quadrant Divider

4.4 SIEVE SHAKER

Sieve analysis was carried out with the help of Ro-Tap reciprocating mechanical sieve shaker to determine the percentage of different grain sizes contained within a sample. The sieve shaker used in the present investigation is shown in Figure 4.4.

Fig. 4.4 Sieve Shaker

4.5 CASAGRANDE APPARATUS

Casagrande apparatus is used for the determination of Liquid Limit. The liquid limit is defined as the moisture content at which the material passes from the plastic state to the liquid state. The liquid limit of the iron ore waste was determined by using Liquid Limit Device Casagrande apparatus available in Geotechnical Laboratory of Civil Engineering Department of the Institute (Fig. 4.5).

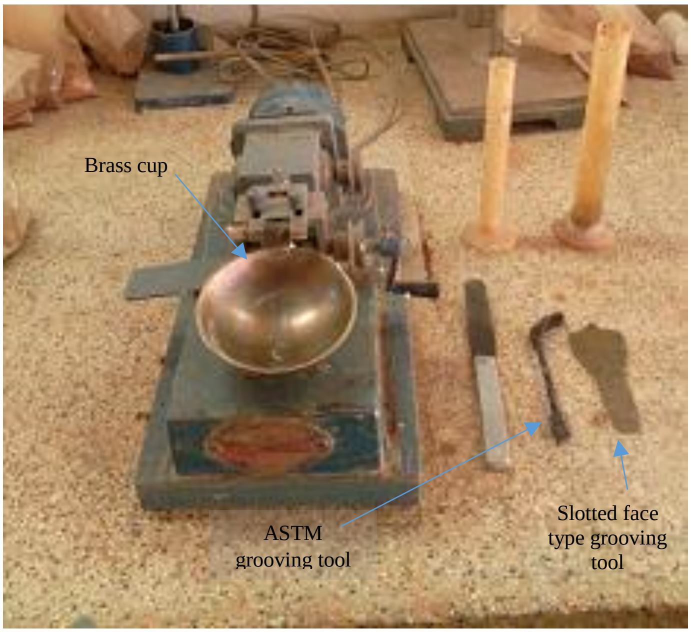


Fig. 4.5 Liquid Limit Device (Casagrande Apparatus)

4.6 DENSITY BOTTLE APPARATUS

Density bottle apparatus (Fig. 4.6) was used for determination of specific gravity of the IOW samples which is available in the Soil Laboratory of the Department of Civil Engineering. It is used only for fine gained materials.

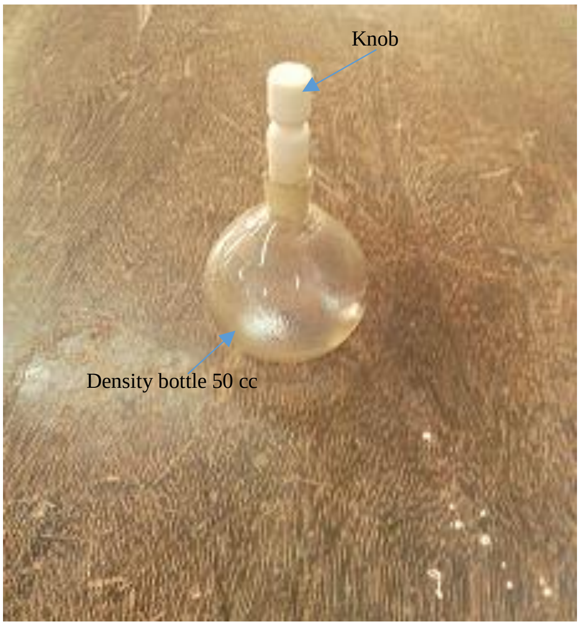


Fig. 4.6 Density Bottle Apparatus

4.7 AUTO FINE COATER

The auto fine coater machine model JEOL-JFC 1600 was used to carry out fine gold coating over the iron, so that the ore can be seen properly (Fig. 4.7). This can also be operated manually to carry out the desired coating. Before carrying out SEM analysis all the samples were gold coated.

Fig. 4.7 Auto Fine Coater

4.8 SCANNING ELECTRON MICROSCOPY (SEM)

Analytical Scanning Electron Microscopy (SEM) model JEOL-JSM-6380 LA was used to perform SEM analysis/SEM microscopy (Fig. 4.8). It has a complete SEM/EDS system, along with energy dispersive X-ray spectroscopy (EDS) capabilities. The equipment uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. In most SEM microscopy applications, data is collected over a selected area of the surface of the sample and a two-dimensional image is generated that displays spatial variations in properties including chemical characterization, texture and orientation of materials. The EDS detector separates the characteristic X-rays of different elements into an energy spectrum. The EDS system software is used to analyse the energy spectrum in order to determine the abundance of specific elements.

Scanning electron microscopy in this investigation was performed at high magnifications, which generates high-resolution images and precisely measures very small features and objects. The purpose of this analysis was to determine the elements present in the collected samples. Some of the salient features of the equipment are:

Resolution: 3.0 nm (Accv:30 kV, WD 8mm Secondary Electron Image)

Minimum magnification: X8 (Accv: 11-30 kV, WD 48 mm or X5 (Accv: 0.5 – 10 kV, WD 48mm)

X-Ray extraction angle: 35˚

SEM controlled user interface software: Version 7.11

Fig. 4.8 Analytical Scanning Electron Microscope

4.9 U-V SPECTROPHOTOMETER

The ultra-violet visible spectrophotometer model U 2000 (Hitachi make) was used to find out the percentage of Fe content in the sample (Fig. 4.9). For all the locations, samples were analysed using this instrument.

Fig. 4.9 U-V Spectrophotometer

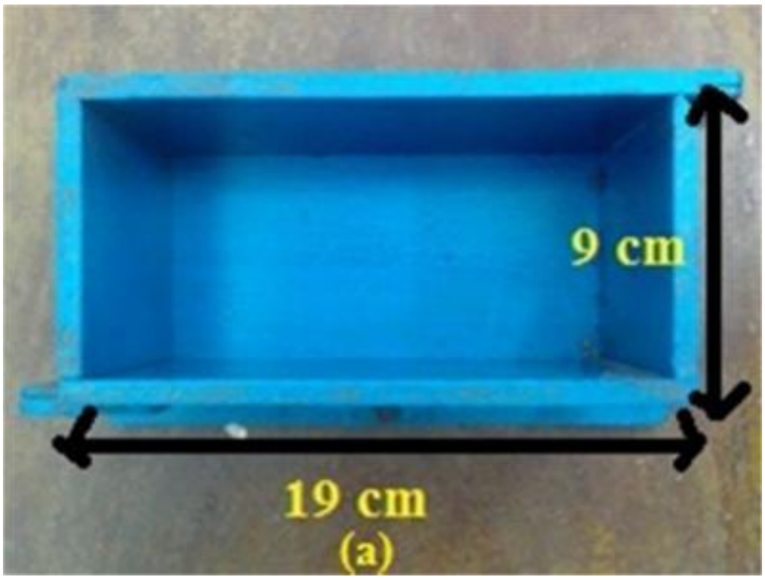
4.10 ATOMIC ABSORPTION SPECTROPHOTOMETER

Model - GBC 932 Plus Atomic Absorption Spectrophotometer (Fig. 4.10) available in the Department of Metallurgical and Materials Engineering of the Institute was used to find the percentage of potassium oxide, magnesium oxide and sodium oxide present in iron ore waste sample (IOW). The data from the instrument can be transferred to a computer (Windows 95) for further processing.

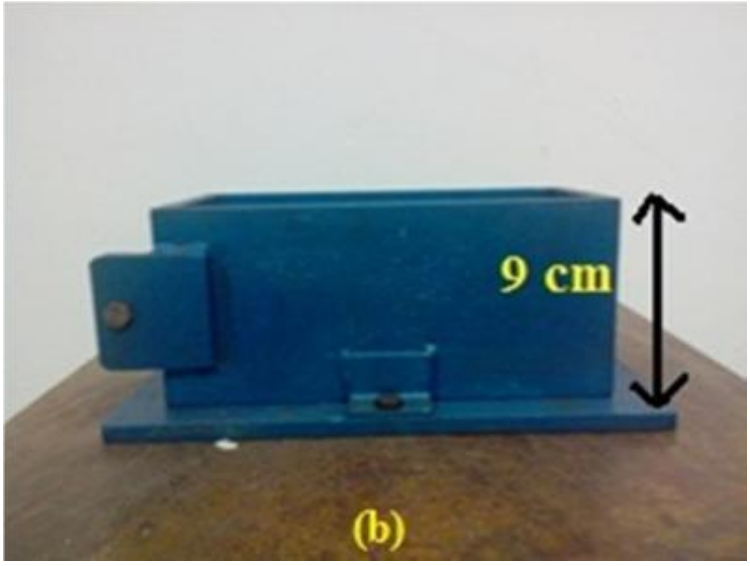
Fig. 4.10 GBC 932 Plus Atomic Absorption Spectrophotometer

4.11 FABRICATED MOULDS FOR BRICK MAKING

Cast iron moulds of internal dimensions 190 mm × 90 mm × 90 mm (IS: 12894-2002) were fabricated for making brick samples (modular type brick). The top view and the two side views of fabricated mould are shown in Figure 4.11a, Figure 4.11b and Figure 4.11c. When the masonry is placed inside the mould, we get bricks of size 19 cm × 9 cm × 9 cm. The cast iron mould with pressing unit is shown in Figure 4.11d. The pressing unit was used to give initial forming load of 15-18 kN for proper compaction of bricks.



(a)



(b)

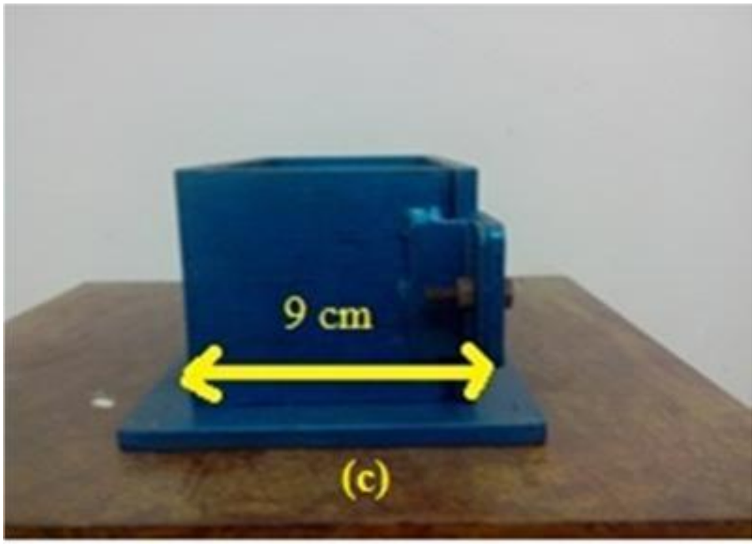


Fig. 4.11 (a), (b) and (c) Different Views of Fabricated Mould

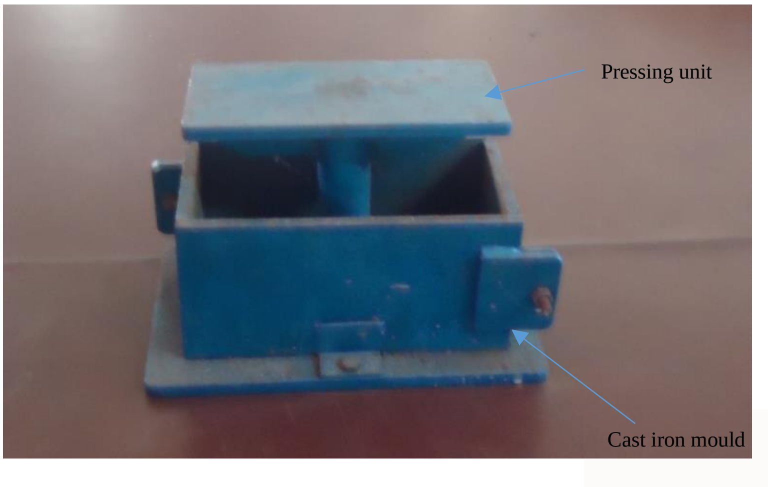


Fig. 4.11 (d) Cast Iron Mould with Pressing Unit Used In Brick Preparation

4.12 AUTOMATED CONCRETE MIXTURE

The automated moveable concrete mixture of capacity 50 kg along with unloading tray and tilting facility was fabricated for this investigation. This apparatus was used to mix the aggregates such as iron ore waste, fly ash and cement in appropriate ratio (Fig. 4.12). The rotating drum which contains aggregates and iron balls is made to rotate for 30 minutes for proper mixing. Once the mixing is done, the mixed material will be unloaded into the collecting tray by tilting the drum vertically down.

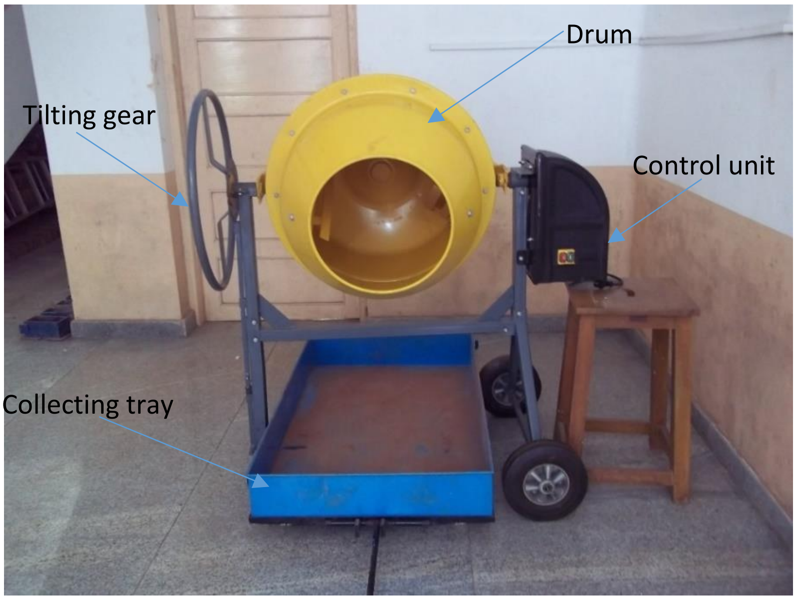


Fig. 4.12 Fabricated Concrete Mixture

4.13 COMPRESSION TESTING MACHINE

Compression testing is one of the most important mechanical property of brick as per Bureau of Indian Standards IS-3495 (Part I):1992. AIM-317E-Mu micro controller compression testing machine was used for measurement of uniaxial compressive strength of bricks (Fig. 4.13).

Fig. 4.13 AIM-317E-Mu, Compression Testing Machine

CHAPTER – 5

5.0 METHODOLOGY

5.1 FIELD INVESTIGATION

5.1.1 Sample Collection for Preliminary Investigation

Iron ore waste samples (silt) were collected from the bottom of the dumps and close to the check dams (as there was water in the check dam), earthen dam and settling tank as per the advice from the concerned mining firm namely M/s Sandur Manganese and Iron Ore Limited (SMIORE). Grab sampling method, which is simplest form of hand sampling was used to collect the sample. A total of nine iron ore waste samples were collected from nine different locations in consultation with the mine management (Table 5.1 and Fig. 5.1). While collecting the sample the top layer of settled silt material was discarded to avoid the unwanted material deposited and the iron ore waste from 3 to 5 cm depth was taken for investigation. Initially around 20 kg of sample each from all the nine locations were brought to determine the material properties as part of preliminary laboratory investigation. Hand held GPS was used for identification of co-ordinates of sample location so that it becomes easier to collect the samples subsequently from the same location.

5.1.2 Sample Collection for Brick Making

After the preliminary laboratory investigation, samples were collected in bulk from six different locations (around 600 kg from each location), which were found to be suitable for further investigation (Fig. 5.2 to 5.7).

Figure 5.2 shows sample being collected from Seelu Kola area which is also called as KMK east. A check dam was constructed by the mine management to stop the dumped material from the prescribed dump area. During rainy season the fine material from the dump gets collected near the check dam which prevents it from getting mixed with river water. The sample was collected just near the check dam. The top layer of settled silt material was discarded and the material from 3 to 5 cm depth was taken for investigation.

Figure 5.3 shows the sample being collected near the old earthen dam at Kaniga Marada Kola, where the top layer of about 5 cm is discarded and then the sample was collected.

Neeru kola is a place very close to a water body. During rainy season the rain water flows towards the water body and brings the material from the dumps which is settled near the kola. The sample was collected using the plucking instrument (Fig. 5.4).

The material at sample location Ankammanal which is a place outside the lease boundary area of SMIORE was very dry. The sample was collected after removing the top soil (Fig. 5.5) using plucking equipment.

Jaldi kola is also known as Yaradammanadari. The sample from this location was collected near the silt settling tank (Fig. 5.6). In a similar way sample was collected from Ram Kola sample location (Fig. 5.7).

Fly ash for the present investigation was collected from a nearby thermal power plant, UPCL (Udupi Power Corporation Ltd.) which was around 10 km from the institute (Fig. 5.8). The commercially available 43 grade Ultra-tech cement was used for in this investigation.

Table 5.1 Coordinates and R.L of Sample Collection Locations

Location	Designation	Description	Coordinates		R.L
Seelu Kolla (SK)	Sample - 1	Toe wall side (bottom)	N14˚59.344'	E76˚34.797'	828 m
Kaniga Marada Kolla (KMK)	Sample – 2	At pit bottom near old earthen check dam	N14˚59.832'	E76 ˚34.081'	922 m
Neeru Kola (NK)	Sample – 3	At pit bottom	N14˚59.911'	E76˚33.399'	867 m
Ankammanal	Sample – 4	At random locations	N14˚59.690'	E76˚31.457'	648 m
JLK (Jaldi Kolla) or Yardammanadari (YRD)	Sample – 5	Silt settling tank	N15˚0.056'	E76˚37.777'	818 m
Governer Point (GP)	Sample – 6	Near earthen dam at existing point	N16˚07.868'	E76˚26.900'	630 m
Gunda Tank	Sample – 7	From tank	N15˚09.110’	E76˚23.378’	522 m
Neer Labbi (NRLB)	Sample – 8	At dump bottom (Nos. D14 and D15)	N15˚04.850’	E76˚28.920’	680 m
Rama Kolla (RMK)	Sample – 9	At flow point	N14˚59.339’	E76˚36.766’	767 m

Fig. 5.1 Google Map Showing Various Sample Locations Using GPS

Fig. 5.2 Collection of Samples at Seelu Kola

Fig. 5.3 Collection of Samples at Kaniga Marada Kola

Fig. 5.4 Collection of Samples at Neeru Kola

Fig.5.5 Collection of Samples at Ankammanal

Fig. 5.6 Collection of Samples at Jaldi Kola

Fig. 5.7 Ram Kola Sample Location

Fig. 5.8 Collection of Fly Ash from UPCL

5.2 LABORATORY INVESTIGATION

The experimental work involved in this investigation was carried out in the Mineral Processing and Rock Mechanics Laboratory of Mining Engineering Department, Geo-technical and Soil Laboratory of Civil Engineering Department, Quality Testing Laboratory and Advanced Instrumentation Laboratory of Chemical Engineering Department and SEM Laboratory of

Metallurgical and Materials Engineering Department of National Institute of Technology Karnataka, Surathkal.

5.2.1 Sampling - Coning and Quartering Method

Sampling is a process of taking representative sample from the given large quantity of sample and is done by various techniques. The coning and quartering technique was adopted in this investigation to carry out the sampling process. To carry out this process, 2000 gm of material was poured into a cone by shovelling all the material to one point on the quartering floor in such a way that the particles roll down in all directions from the central point. Irregularities in the composition of the mass are thus distributed as concentric layer of the cone. The top of the cone is then flattened with the edge of the shovel by spreading the material equally in all directions until a disc is formed. This disc is made into quadrants with the help of quadrant divider and the diagonally opposite quarters were cut out and all the material in the rejected quadrants removed. The mass now contains half the original quantity of the sample. The above mentioned process was repeated till one fourth of the original mass is obtained i.e. 500 gm. The sampling process of coning and quartering is shown in Figure 4.3 of Chapter 4 on INSTRUMENTS.

5.2.2 Sieve Analysis

Sieve analysis was carried out in the Mineral Processing Laboratory of the Department of Mining Engineering. It gives an idea about the size distribution of particles in a given sample. The methodology of sieve analysis was as per IS 2720 (Part IV):1985.

In simple words, sieve analysis is a method of size analysis. It is performed to determine the percentage weight of closely sized fraction by allowing the sample of material to pass through a series of test sieves. Sieve analysis was carried out using a sieve shaker namely Ro-tap reciprocating sieve shaker as discussed in Chapter 4 on INSTRUMENTS. The sieves chosen for the test were arranged in a stack, starting from the coarsest sieve at the top and the finest at the bottom. A pan or receiver was placed below the bottom sieve to receive final undersize, and a lid was placed on top of the coarsest sieve to prevent escape of the sample. The material to be tested (500 gm) was placed on uppermost coarsest sieve and closed with a lid. The set of test sieves was then placed in a sieve shaker and sieved for 20 minutes duration.

The material collected on each sieve was removed and weighed. The complete set of values obtained are known as Particle Size Distribution data. The particle size distribution refers to the manner in which the particles are quantitatively distributed among various sizes; in other words a statistical relation between quantity and size.

The weight percentages of the material retained on each sieve were determined from which the cumulative weight percentage retained and cumulative weight percentage passed was calculated.

5.2.3 Material Properties

To carry out the process of testing of material properties, it is very much necessary to remove the moisture content from the collected sample. To remove the moisture content from the sample, around 5 kg of each sample from all the nine locations was taken and kept in RoTek make hot air oven (Fig. 4.2 of Chapter - 4) at 110˚C for 8-10 hours duration.

The various analysis which were carried out on the materials were:

Iron ore waste: - Sieve analysis, Atterbergs limit, Chemical composition and specific gravity.

Cement: - Chemical composition and specific gravity.

Fly-ash: - Chemical composition and specific gravity.

5.2.3.1 Atterberg Limit

A. Liquid limit

The liquid limit of iron ore waste was determined by using Casagrande Apparatus described earlier in Chapter 4 on INSTRUMENTS. It was analysed according to the IS: 2720 (Part 5):1985.

In this method, a paste of iron ore waste was placed in the Casagrande cup. A groove was then cut at the centre of the iron ore waste pat using standard grooving tool. With the help of crank operated cam, the cup was lifted and dropped from a height of 1cm. A flow curve was plotted with moisture content and number of blows required at close distance of 12.7 mm along the bottom of the groove. The liquid limit is the moisture content corresponding to 25 number of blows in a flow curve.

B. Plastic Limit

This test was done to determine the plastic limit of IOW sample as per IS: 2720 (Part 5) – 1985.The plastic limit of fine-grained material is the water content of the material below which it ceases to be plastic. It begins to crumble when rolled into threads of 3 mm diameter.

Sample was prepared by taking 30 gm of air-dried IOW sample passing through 425μm IS sieve. The sample was then mixed with distilled water in an evaporating dish. Sample of mass around 8 gm was taken and rolled with fingers on a glass plate to form approximately 3 mm diameter threads (Fig. 5.9). If the diameter of the threads can be reduced to less than 3 mm without any cracks appearing, it means that the water content is more than its plastic limit. In such case, to reduce the water content, the sample is kneaded and rolled again. This process was repeated for alternate rolling and kneading until the thread crumbles. All the crumbled threaded sample was collected and kept in the container used to determine the moisture content. The average water content to the nearest whole number was noted as the plastic limit.

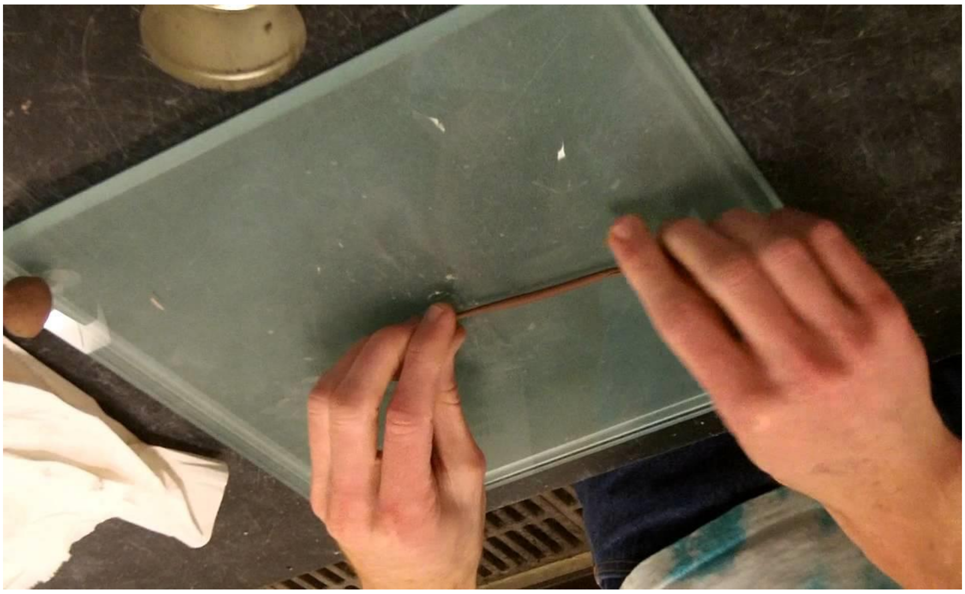


Fig. 5.9 Threaded sample (3 mm dia.)

C. Shrinkage Limit

This test was done to determine the shrinkage factor of IOW sample as per IS: 2720 (Part VI) – 1985.

As the soil loses moisture, either in its natural environment, or by artificial means in laboratory it changes from liquid state to plastic state to semi-solid state and then to solid state. The volume is also reduced by the decrease in water content. But, at a particular limit the moisture reduction causes no further volume change. The shrinkage limit is useful in areas where soils undergo large volume changes when going through wet and dry cycles (e.g. earthen dams). The shrinkage limit test set up is shown in Figure 5.10.

To carry out determination of shrinkage factor of IOW sample, the following steps were followed:

1. 100 gm. of IOW sample from a thoroughly mixed portion of the material passing through 425 micron IS sieve was taken.
2. About 30 gm. of above IOW sample was placed in an evaporating dish and thoroughly mixed with distilled water to make a paste.
3. The weight of the clean empty shrinkage dish was recorded.
4. The shrinkage dish was filled in three layers by placing approximately 1/3rd of the amount of wet IOW sample with the help of spatula.
5. Then the dish with wet IOW sample was weighed and the reading was recorded.
6. The wet IOW pat cake was air dried until the colour of the pat turns from dark to light. Then it was oven dried at a temperature of 105^0C to 110^0C for 12 to 16 hours. The weight of the shrinkage dish with dry IOW pat was calculated (W_0).
7. The shrinkage dish was placed in the evaporating dish and the dish was filled with mercury, till it overflows slightly. Then it was pressed with plain glass plate firmly on its top to remove excess mercury. The mercury from the shrinkage dish was poured into a measuring jar and the volume of the shrinkage dish was calculated. This volume is recorded as the volume of the wet IOW pat (V).
8. A glass cup was placed in a suitable large container and the glass cup removed by covering the cup with glass plate with prongs and pressing it. The outside of the glass cup was wiped to remove the adhering mercury. Then it was placed in the evaporating dish which was cleaned and made empty.
9. Then the oven dried IOW pat was placed on the surface of the mercury in the cup and pressed by means of the glass plate with prongs, the displaced mercury being collected in the evaporating dish.

10. The mercury so displaced by the dry IOW pat was weighed and its volume (V_0) was calculated by dividing this weight by unit weight of mercury.

The shrinkage limit was calculated by using the following formula

Shrinkage limit (Ws) = $\frac{V - V_0}{W_0}$ X 100

where, W = Moisture content of wet IOW pat

The test was repeated 3 times for each IOW sample and the average of the result was recorded and presented in this thesis in Results and Discussion.

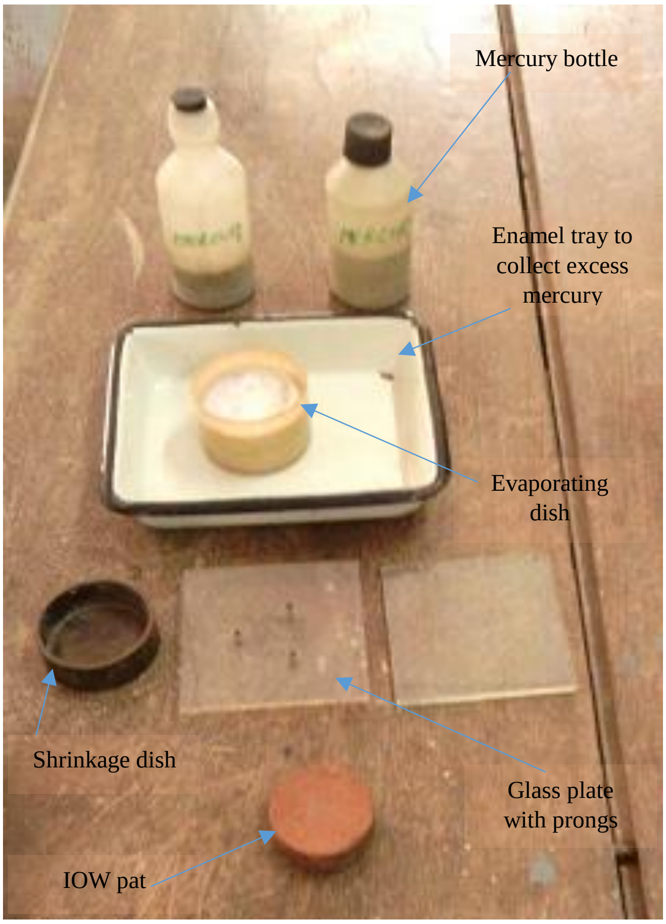


Fig. 5.10 Shrinkage limit test set up

5.2.3.2 Specific Gravity

Specific gravity test for cement, iron ore waste and fly-ash was carried out by using Density

Bottle Apparatus described in the Chapter on INSTRUMENTS. The test was carried out as per IS-2720 (Part III/Sect.2):1980.

The specific gravity of solid particles is the ratio of the mass density of solids to that of water and it is determined in the laboratory using the relation.

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

where,

M_1 = mass of empty bottle
M_2 = mass of the bottle and dry soil
M_3 = mass of bottle, soil and water
M_4 = mass of bottle filled with water only.

The following procedure was followed to determine the specific gravity of Iron ore waste sample.

a. Wash the density bottle (50 ml capacity) and dry it in an oven at 105^0C to 100^0C and then cool it in the desiccator.
b. Weight of the density bottle with stopper was taken to the nearest 0.001g (M_1).
c. IOW Sample of 10 gm (oven dried) was taken and transferred it in the density bottle. Weigh the bottle with the stopper and the dry sample was taken (M_2).
d. Distilled water was added to the density bottle, just enough to cover the sample. Mixing was done by gently shaking the density bottle to mix the sample and water.
e. Bottle containing the soil and water after removing the stopper was placed in the vacuum desiccator.
f. The desiccator was evacuated gradually by operating the vacuum pump. Pressure was reduced to about 20 mm of mercury. Bottle was kept in the desiccator for at least 1 hour or until no further movement of air was noticed.
g. Vacuum was replaced and lid of the desiccator was removed. The soil in the bottle sample was stirred carefully with the help of spatula. The particles of the sample adhering to it was washed off with a few drops of air free water. The lid of the desiccator was replaced and again vacuum was applied. This procedure was repeated until no more air was evolved from the sample.

h. The bottle from the desiccator was removed and air-free water was added until the bottle is full and then the stopper was inserted.
i. The bottle was immersed up to the neck in a constant-temperature bath for approximately 1 hour or until it has attained the constant temperature.
j. The bottle was taken out from the water bath, wiped and dried.
k. The mass of the bottle and its contents were determined (M_3).
l. The bottle was made empty and cleaned thoroughly. Distilled water was filled and stopper was inserted.
m. The bottle was then immersed in a constant-temperature bath for 1 hour or until it has attained the constant temperature of the bath.
n. The bottle was taken out from the water bath, wiped and dried. The mass was taken as (M_4).
o. Based on M_1, M_2, M_3 and M_4 obtained as above, the specific gravity of the materials involved in this research work was calculated.

5.3 ANALYSIS OF IOW SAMPLES

The chemical composition of iron ore waste (IOW), fly ash and cement was carried out in Quality Testing Laboratory and Advanced Instrumentation Laboratory of Chemical Engineering Department at NITK, Surathkal. From the representative sample of 125 gm obtained through the process of coning and quartering, 100 gm of each sample was taken for subsequent chemical analysis.

5.3.1 Chemical Analysis

The determination of SiO_2, R_2O_3, Al_2O_3 and CaO was done by Digestion Method whereas Na_2O, K_2O and MgO were determined by Atomic Absorption Spectroscopy and Fe_2O_3 by UV Spectrophotometer.

To carry out chemical analysis of iron ore waste, it is very much necessary to convert IOW which is in powder form into liquid form. For this purpose, 1gm of sample was taken in a beaker. To this sample, 10 ml of hydrochloric acid (HCL), 10 ml of water and 5 ml of nitric acid was added (Fig. 5.11). The beaker was then kept in a fume chamber to digest the material for more than 24 hrs. After the process of digestion, using distilled water the sample was filtered using Whatman filter paper as shown in Fig. 5.12 and the beaker was washed thoroughly by using distilled water 4 to 6 times. This is done in such a way so as to obtain a 500 ml solution for further process (Process 1).

Fig. 5.11 Digested sample for filtration

Fig. 5.12 Filtration process

A). Silica (SiO_2):

After the above mentioned filtration process (Process 1), the filter paper was taken out in a known weight of the crucible (W1) and was ignited using bunsen burner. After burning the filter paper, weight of the crucible was again taken (W2). The percentage of silica content was obtained using:

$$\text{Silica \%} = \frac{\text{W2}-\text{W1}}{\text{Sample weight taken}} * 100$$

B) R_2O_3:

From 500 ml of the solution obtained in process (1), 100 ml of solution was taken out using pipette and was warmed. This 100 ml of solution was precipitated (jelly form) by adding ammonia solution. Filtration of the solution was done using whatman 42 filter paper as shown in Figure 5.13 and the filter paper was washed using ammonium nitrate. The filtrated solution was made up to 250 ml using distilled water. Weight of the empty crucible (W1) and crucible with filter paper (W2) was noted. With the help of below equation, the percentage of R_2O_3 was obtained.

$$R_2O_3\ \%= \frac{\text{W2}-\text{W1}}{\text{Sample wieght taken}} * 100 * \text{dilution factor}$$

where, Dilution factor = 5

Fig. 5.13 Filtration process to find R_2O_3

C) IRON (Fe_2O_3)

From 500 ml of solution obtained in process (1), 1 ml of the solution was taken. To this 1 ml solution, 0.1ml of thioglycolic acid, 2 ml of 20 % citric acid mix, and 5 ml of aqueous ammonia (10 % or sufficient to render distinctly alkaline) was added. The solution was made up to 50 ml using distilled water. The presence of Fe content was found using UV-spectrophotometer at 540 nm as discussed in Chapter 4 on INSTRUMENTS, using the above obtained solution. Further, Fe value was converted to Fe_2O_3 by the following equation.

$$Fe = \frac{\text{Photometer value}}{\text{Sample wieght taken}} * 0.1 * \frac{100}{1000} * \text{dilution factor}$$

where,

0.1 = standard value of ion

Fe_2O_3 = Fe x Conversion factor (1.4292)

Dilution factor = 500

D) Aluminium (Al_2O_3):

With the help of the results of R_2O_3 and Fe_2O_3 obtained above, the presence of Al_2O_3 percentage was found out using:

Al_2O_3 (%) = R_2O_3 - Fe_2O_3

E) Calcium oxide (CaO):

From 500 ml of solution obtained in process (1), 100 ml of solution was taken out using pipette and two drops of methyl orange indicator was added to it. This 100 ml of solution was acidified with hydrochloric acid (HCl) and it was warmed (approx. 30 minutes) till it attains red colour. The above solution was precipitated by adding 15 ml of saturated ammonium oxalate. Wait for an hour and filter using whatman 42 filter paper. Wash the filter paper thoroughly 8 to 10 times with ammonia water. Transfer the filter paper into beaker and add 50 ml of 2 N sulphuric acid and warm until the filter paper gets dissolved in the solution. Titrate using $KMnO_4$ till its colour changes to pink (Titration 1).

To find the Normality:

Take out 20 ml of 2N sulphuric acid and add 10 ml of oxalic acid (0.1N) and keep it in a fume chamber.

$$\text{Calcium oxide (CaO) \%} = \frac{\text{Reading from the titration}}{\text{Sample wieght taken}} * normality * 28 * \frac{100}{1000} * \text{dilution factor}$$

where,

28 is the molecular weight of CaO

Dilution factor = 12.5

Determination of Na_2O, K_2O and MgO was carried out by Atomic absorption spectroscopy (AAS). This method consists of preparing a series of standard solutions containing the element to be determined and of preparing solutions of metallic alloy samples and then measuring the absorption of light by the atoms of the element when the solutions are aspirated into a flame. Atomic Absorption Spectrophotometer GBC Model 932 Plus discussed in the Chapter 4 on INSTRUMENTS was used for determination of sodium oxide, magnesium oxide and potassium oxide.

F) Sodium oxide (Na_2O):

For determination of sodium oxide, 1000 µg/ml standard solution has to be prepared. To do this, dissolve 2.5420 gm of dry NaCl in distilled water and dilute to 1 litre to obtain 1000 µg/ml Na. The lamp current used in the Atomic Absorption Spectrophotometer was 5.0 mA and flame type was air acetylene (oxidizing). The optimum wavelength used was 589.0 nm with slit width 0.5 nm.

Reading from atomic absorption is = 1.6

$Na_2O = 1.6 * 500 / 1 \Rightarrow ans * 100 / 10^6 \Rightarrow ans * (31 / 23)$

where,

31 / 23 is multiplication factor to get in oxide form.

500 is main stock of solution taken (1ml of solution to test)

G) Potassium oxide (K_2O):

For determination of potassium oxide too, 1000 µg/ml standard solution is prepared. This is done by dissolving 1.9067 gm of dry KCI in distilled water and then diluting it to 1 litre to obtain 1000 µg/ml K. The lamp current used in this case was 6.0 mA and flame type was air acetylene (oxidizing). The optimum wavelength used was 766.5 nm with slit width 0.5 nm.

Reading from atomic absorption is = 1.9

$K_2O = 1.9 * 500 / 1 \Rightarrow ans * 100 / 10^6 \Rightarrow ans * (47 / 39)$

where,

47 / 39 is multiplication factor to get in oxide form.

500 is main stock of solution taken (1 ml of solution to test).

H) Magnesium oxide (MgO):

For preparation of 1000 µg/ml standard solution, dissolve 1.0 gm of magnesium metal in 50 ml of 5N hydrochloric acid and dilute to 1 litre to obtain 1000 µg/ml Mg. The lamp current used here was 3.0 mA and flame type was air acetylene (oxidizing). The optimum wavelength used was 285.2 nm with slit width 0.5 nm.

Reading from atomic absorption is = 1.022

MgO = 1.022 * 500 / 1 => ans * 100 / 10^6 => ans * (30.3 / 24.3)

where,

0.1 is solution taken from the main stock.

30.3 / 24.3 is multiplication factor to get in oxide form

5.3.2 Analysis of IOW Using Scanning Electron Microscope (SEM)

The chemical analysis of IOW sample was carried out using SEM model Jeol-JSM-6380 LA Analytical Scanning Electron Microscope and JFC- 1600 Auto Fine-Coater described earlier in Chapter 4 on INSTRUMENTS.

To carry out the SEM analysis process, 1 gm of IOW sample was gold coated using JFC- 1600 Auto Fine Coater and was used in SEM analysis. This process was done for all the nine samples collected from different locations. The images of iron ore waste from SEM instrument JEOL JSM-6380 LA was analysed with the help of SEM control user interface software Version 7.11. The morphological structure of each material was studied with this analysis. The Energy Dispersive X-ray Spectroscopy (EDAX) was also done for all nine different samples to analyse the major phase in the materials.

5.4 BRICK PREPARATION

The general steps involved in preparation of iron ore waste (IOW) bricks consist of the following steps:

a) Collecting the iron ore waste sample from the field

b) Mixing of additives with iron ore waste (fly ash and cement)

c) Preparing the bricks in fabricated mould

d) Curing the prepared bricks

5.4.1 Collecting the Iron Ore Waste Sample from the Field

As discussed earlier in this chapter, initially samples were collected for preliminary investigation from nine different locations as mentioned in Table 5.1 and Figure 5.1. However, for actual brick making, bulk samples were collected from six different locations of the order of 600 kg from each location. The details of these six sample locations has already been discussed in Section 5.1.2 of this Chapter. From three locations samples were not collected. They are Governer Point (GP), Gunda Tank and Neer Labbi (NRLB) designated respectively as Sample – 6, Sample – 7 and Sample – 8 respectively (Table 5.1). Samples for brick making from these three locations were not considered as the preliminary investigation has revealed that "Fe_2O_3" percentage in these locations was 30 % and above. It was felt that these material can be used as ore in near future based on iron ore demand and also on improvement of ore upgradation technology.

5.4.2 Mixing of Additives with Iron Ore Waste (Fly Ash and Cement)

As all the collected iron ore waste (IOW) sample was in the form of powder (less than 300 µ), it did not require further processing like crushing and grinding. Hence, the collected samples were directly suitable for mixing with additives for brick making. For preparing the bricks, iron ore waste was taken as a major aggregate in combination with fly ash and cement. Five different combinations of above said aggregates i.e. cement, fly ash and iron ore waste by mass percentage as given in Table 5.2 to Table 5.7 were used in brick preparation. In the composition of mixture for brick making, the bricks were prepared with IOW of 65, 70, 75, 80, 85 and 90 percentage. The different mixtures prepared with IOW of 65 % was named as A to F (Table 5.2). Similarly, the mixtures prepared with IOW of 70 % was named as A1 to E1 (Table 5.3), IOW of 75 % as A2 to D2 (Table 5.4), IOW of 80 % as A3 to C3 (Table 5.5), IOW of 85 % as A4 to B4 (Table 5.6) and IOW of 90 % as A5 (Table 5.7).

Table 5.2 Composition for different types of mixes with IOW 65 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A	30	05	65
B	25	10	65
C	20	15	65
D	15	20	65
E	10	25	65
F	05	30	65

Table 5.3 Composition for different types of mixes with IOW 70 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A1	30	00	70
B1	25	05	70
C1	20	10	70
D1	15	15	70
E1	10	20	70

Table 5.4 Composition for different types of mixes with IOW 75 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A2	25	00	75
B2	20	05	75
C2	15	10	75
D2	10	15	75

Table 5.5 Composition for different types of mixes with IOW 80 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A3	20	00	80
B3	15	05	80
C3	10	10	80

Table 5.6 Composition for different types of mixes with IOW 85 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A4	15	00	85
B4	10	05	85

Table 5.7 Composition for different types of mixes with IOW 90 %

Mixture	Ratio (in %)		
	Cement (C)	Fly-ash (FA)	Iron Ore Waste (IOW)
A5	10	00	90

5.4.3 Preparing the Bricks in Fabricated Mould

Bricks were prepared using 30 cast iron metallic moulds which were specifically fabricated for this purpose. The details about the fabricated mould is discussed earlier in Chapter 4 on INSTRUMENTS. The required mixtures as given in Table 5.2 to Table 5.7 were mixed thoroughly using the fabricated Automated Moveable Concrete Mixture of capacity 50 kg which is again discussed in detail in Chapter 4 on INSTRUMENTS.

During the process of brick making, oil was applied to the inner part of the mould and the prepared mixture from Automated Moveable Concrete Mixture was poured slowly into it so that it spreads evenly inside the mould. It was covered with the pressing unit and was hammered for proper compaction of material in the mould. After filling the mould with the required mixture, load up to 20 MPa was applied (based on the earlier studies carried out by various investigators, Yongliang et al. 2011) using AIM-317E-Mu Micro Controller Compression Testing Machine discussed in detail in Chapter 4 on INSTRUMENTS. This was done for the purpose of proper compaction of bricks. The size of bricks prepared was 190 mm × 90 mm × 90 mm which was as per IS-2691:1988.

5.4.4 Curing the prepared bricks

The prepared bricks were kept for 24 hours in the mould and then removed and kept under sunlight for drying. Proper curing was done by spraying water for 7days, 14 days, 21 days and 28 days, as shown in Figure 5.14.

Fig. 5.14 Curing of bricks

5.5 ASSESSMENT OF QUALITY OF BRICKS

The quality of bricks was assessed as per BIS Standards which is based on compressive strength [IS 3495 (Part I): 1992] and water absorption of the bricks [IS 3495 (Part II): 1992]. The compressive strength should always be more than or equal to 35 kg cm^{-2} or 3.5 MPa and the water absorption of a good brick should be less than 20 % after 24 hours of immersion in water.

5.5.1 Compressive Strength

For each number of curing days, five bricks were tested for its compressive strength. The compressive strength of the bricks were determined using AIM-317E-Mu Micro Controller Compression Testing Machine discussed in detail in Chapter 4 on INSTRUMENTS. Axial load on the bricks was applied at a uniform rate of 14 N/mm^2 per minute till the failure. The maximum load at failure was recorded. This procedure for testing of compressive strength was followed for of all sets of prepared bricks.

5.5.2 Water Absorption

To determine the water absorption capacity of different bricks, a bucket with known quantity of water and electronic weighing balance was used. Initially the weight of the dry bricks (dry weight) was taken. The bricks were then immersed in a container which was filled with water for 24 hours at room temperature (Fig. 5.15). After 24 hours, the bricks were taken out of the container and excess water on the surface of the bricks was cleaned using tissue paper. The final weight of the brick was taken to calculate the percentage of water absorption. For each number of curing days, five bricks were tested for its water absorption. This procedure for testing of water absorption was followed for of all sets of prepared bricks.

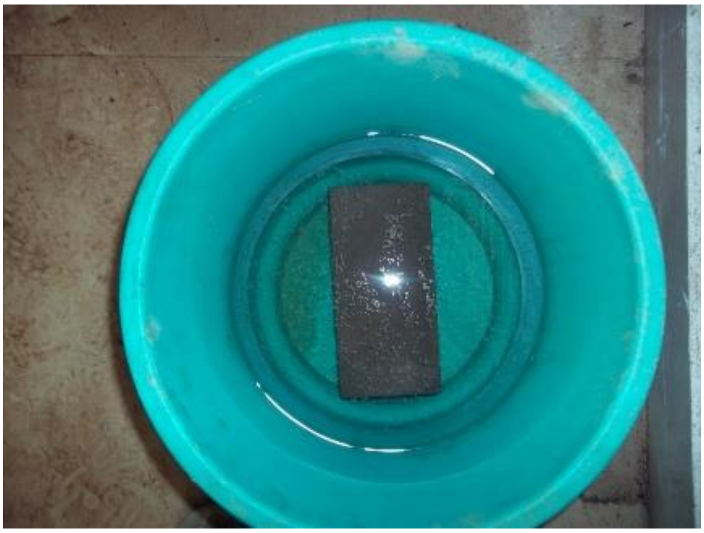


Fig. 5.15 Water Absorption Test

5.6 BRICK DENSITY

The density test was carried out using hot air oven and electronic weighing balance available in the Department of Mining Engineering. The bricks were initially dried in a hot air oven at a temperature of 105^0 to 115^0C till it attains substantially constant mass. The bricks were then cooled to room temperature and its mass was recorded (M). The dimensions of the brick was measured accurately and the volume was calculated (V). The density was calculated as mass per unit volume.

CHAPTER – 6

6.0 RESULTS AND DISCUSSION

6.1 SPECIFIC GRAVITY

The results of the specific gravity of the materials which was carried out in the laboratory using Density bottle apparatus is given in Table 6.1. It is clearly evident that cement is having the highest specific gravity followed by iron ore waste and then fly ash.

Table 6 .1 Specific gravity of the materials

Materials	Specific gravity
Cement	3.15
Iron ore waste	3.18
Fly ash	1.90

6.2 ATTERBERG LIMIT

The Atterberg Limit consists of determination of Liquid Limit, Plastic Limit, Plasticity Index and Shrinkage Limit of the iron ore waste. The percentage of water content in iron ore waste at 25 blows is shown in the flow curve (Fig. 6.1). The results of the Atterberg Limit on iron ore waste is given in Table 6.2.

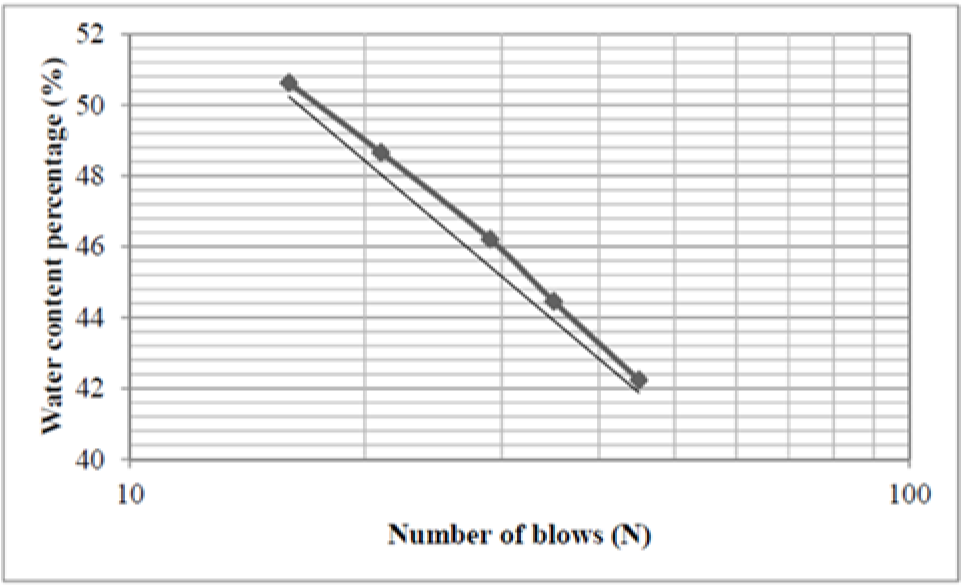


Fig. 6.1 Percentage of water content in iron ore waste at 25 blows

Table 6.2 Atterberg limits of iron ore waste

Atterberg limits	Percentage (%)
Liquid limit	48
Plastic limit	28
Plasticity index	20
Shrinkage limit	18

6.3 SIEVE ANALYSIS

Table 6.3 to 6.11 gives the results of sieve analysis on nine different samples performed using the mechanical sieve shaker with 500 gm sample each. Figure 6.2 to Figure 6.10 shows the respective graphs plotted for cumulative percentage of weight retained (Y- axis) and sieve size (X – axis).

The results of sieve analysis shows that in samples S2, S3, S4, S6, S8 and S9 more than 90 % of the material passed through 600 µm sieve size whereas, in sample S1, S5 and S7 around 80 % of material passed through 600 µm sieve size. Hence, the collected material can be directly (without sieving) used in brick preparation. This not only saves energy and power consumption but also saves time.

Table 6.3 Sieve analysis data for Sample-1

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	1.20	498.80	0.240	0.240	99.760
2360	3.20	495.60	0.640	0.880	99.120
1180	24.42	471.18	4.884	5.764	94.236
600	76.96	394.22	15.392	21.156	78.844
300	67.82	326.40	13.564	34.720	65.280
150	211.80	114.60	42.360	77.080	22.920
75	85.80	28.80	17.160	94.240	5.760
-75	28.80	0.00	5.760	100.000	0.000

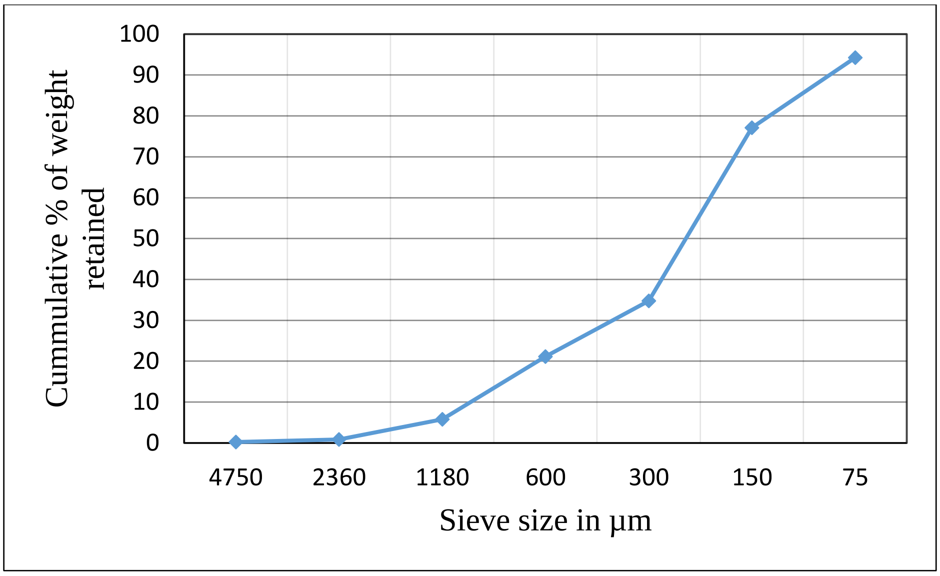


Fig. 6.2 Cumulative percentage retained vs. sieve size for Sample-1

Table 6.4 Sieve analysis data for Sample-2

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	7.0	493.0	1.40	1.40	98.60
600	29.4	463.6	5.88	7.28	92.72
300	235.4	228.2	47.08	54.36	45.64
150	130.8	97.4	26.16	80.52	19.48
75	79.6	17.8	15.92	96.44	3.56
-75	17.8	0.0	3.56	100.00	0.00

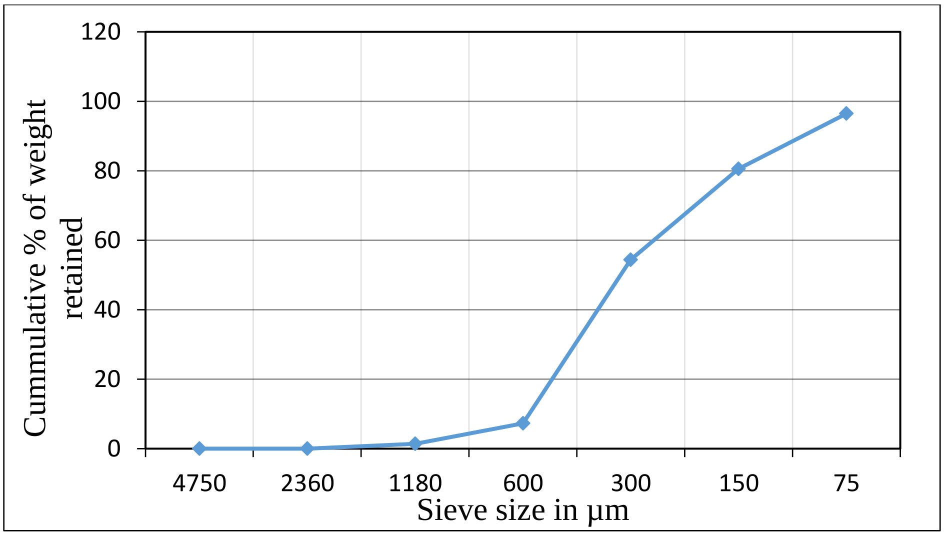


Fig. 6.3 Cumulative percentage retained vs. sieve size for Sample-2

Table 6.5 Sieve analysis data for Sample-3

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	0.0	500.0	0.00	0.00	100.00
600	8.4	491.6	1.68	1.68	98.32
300	30.6	461.0	6.12	7.80	92.20
150	345.8	115.2	69.16	76.96	23.04
75	75.8	39.4	15.16	92.12	7.88
-75	39.4	0.0	7.88	100.00	0.00

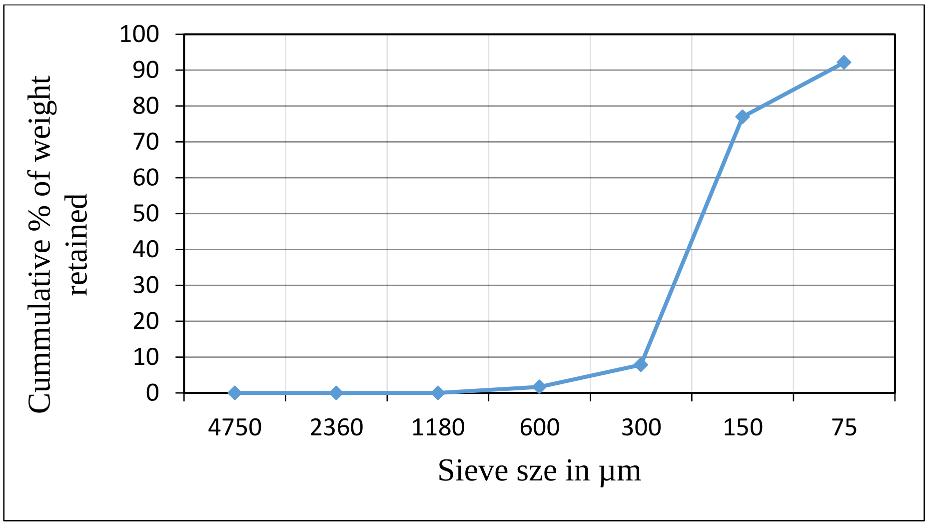


Fig. 6.4 Cumulative percentage retained vs. sieve size for Sample-3

Table 6.6 Sieve analysis data for Sample-4

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	1.6	498.4	0.32	0.32	99.68
600	8.8	489.6	1.76	2.08	97.92
300	68.2	421.4	13.64	15.72	84.28
150	36.6	384.8	7.32	23.04	76.96
75	168.6	216.2	33.72	56.76	43.24
-75	216.2	0.0	43.24	100.00	0.00

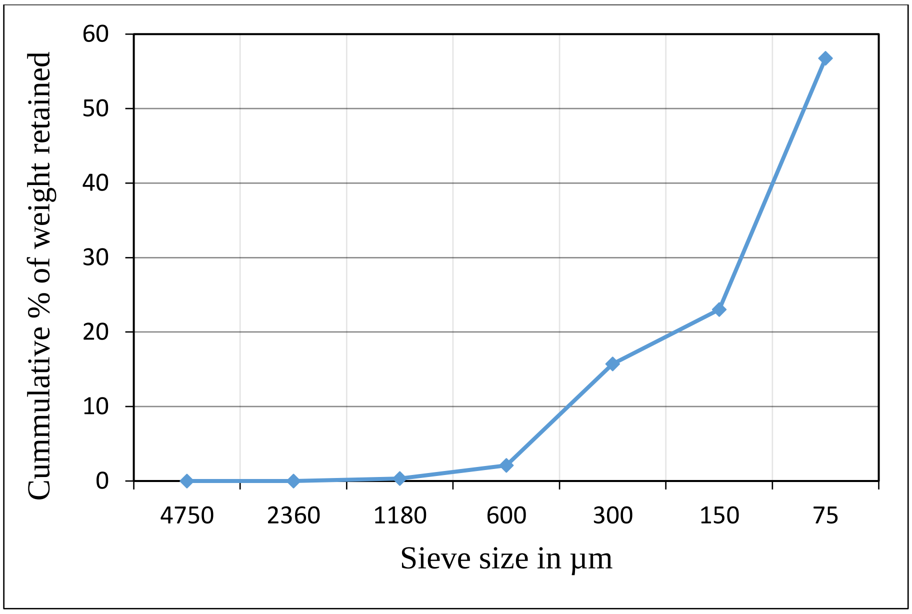


Fig. 6.5 Cumulative percentage retained vs. sieve size for Sample-4

Table 6.7 Sieve analysis data for Sample-5

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.8	499.2	0.16	0.16	99.84
1180	3.8	495.4	0.76	0.92	99.08
600	68.4	427.0	13.68	14.60	85.40
300	86.6	340.4	17.32	31.92	68.08
150	172.4	168.0	34.48	66.40	33.60
75	115.4	52.6	23.08	89.48	10.52
-75	52.6	0.0	10.52	100.00	0.00

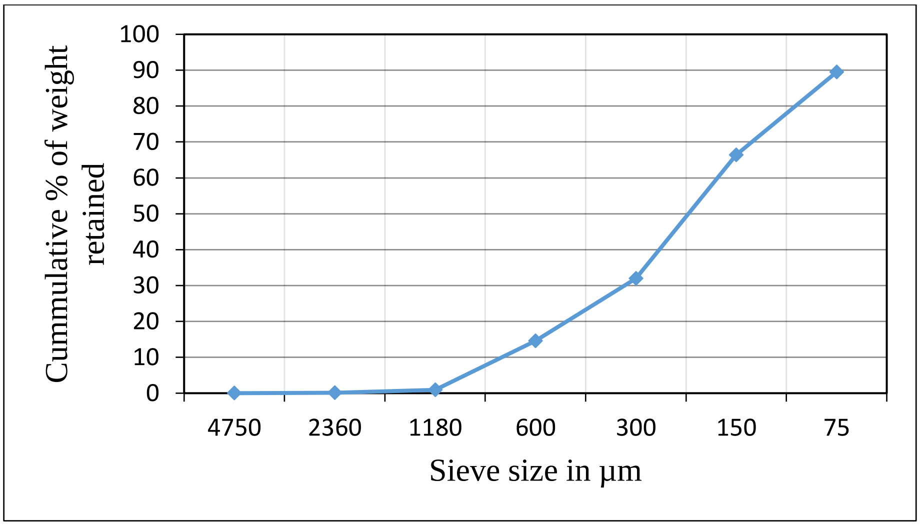


Fig. 6.6 Cumulative percentage retained vs. sieve size for Sample-5

Table 6.8 Sieve analysis data for Sample-6

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	0.0	500.0	0.00	0.00	100.00
600	1.6	498.4	0.32	0.32	99.68
300	53.0	445.4	10.60	10.92	89.08
150	135.6	309.8	27.12	38.04	61.96
75	182.4	127.4	36.48	74.52	25.48
-75	127.4	0.0	25.48	100.00	0.00

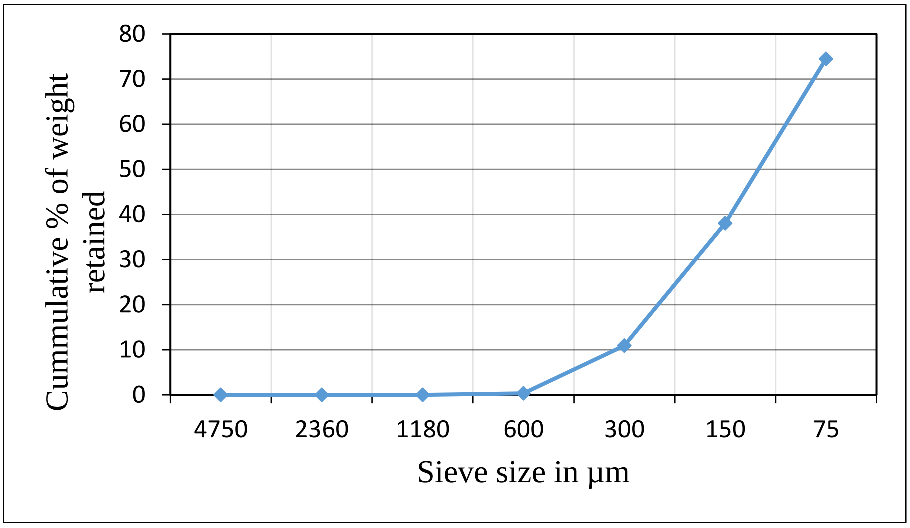


Fig. 6.7 Cumulative percentage retained vs. sieve size for Sample-6

Table 6.9 Sieve analysis data for Sample-7

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	5.8	494.2	1.16	1.16	98.84
600	95.0	399.2	19.00	20.16	79.84
300	133.2	266.0	26.64	46.80	53.20
150	165.8	100.2	33.16	79.96	20.04
75	74.4	25.8	14.88	94.84	5.16
-75	25.8	0.0	5.16	100.00	0.00

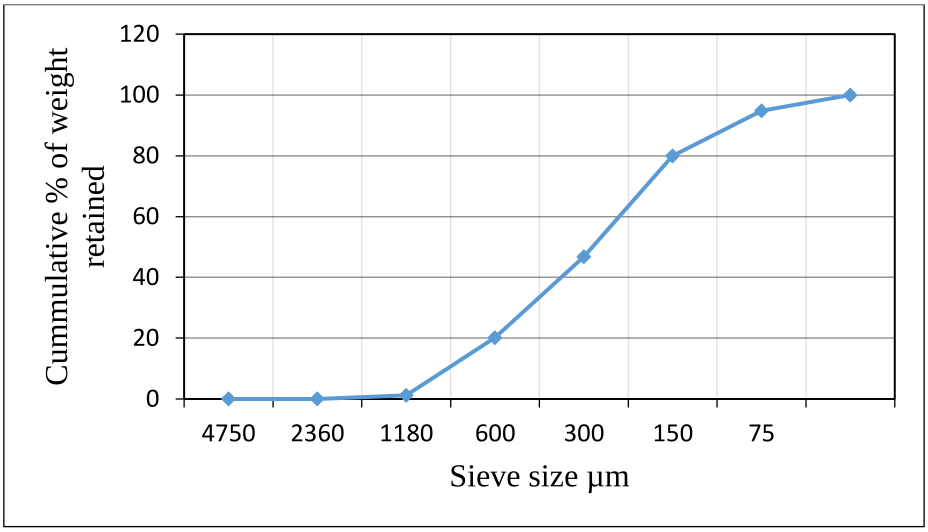


Fig. 6.8 Cumulative percentage retained vs. sieve size for Sample-7

Table 6.10 Sieve analysis data for Sample-8

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	0.0	500.0	0.00	0.00	100.00
600	4.8	495.2	0.96	0.96	99.04
300	17.8	477.4	3.56	4.52	95.48
150	56.6	420.8	11.32	15.84	84.16
75	184.4	236.4	36.88	52.72	47.28
-75	236.4	0.0	47.28	100.00	0.00

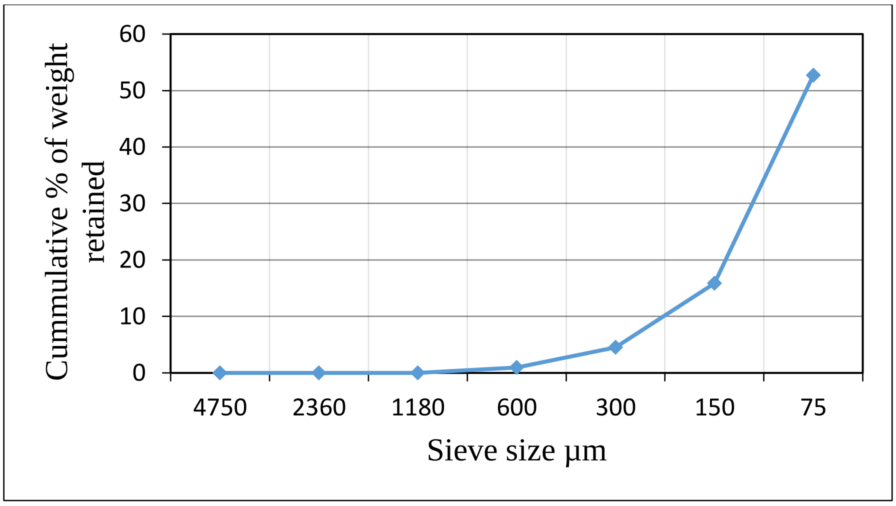


Fig. 6.9 Cumulative percentage retained vs. sieve size for Sample-8

Table 6.11 Sieve analysis data for Sample-9

Sieve size	Retained weight	Passing weight	Percentage retained	Cumulative percentage retained	Cumulative percentage passed
4750	0.0	500.0	0.00	0.00	100.00
2360	0.0	500.0	0.00	0.00	100.00
1180	21.2	478.8	4.24	4.24	95.76
600	15.6	463.2	3.12	7.36	92.64
300	47.6	415.6	9.52	16.88	83.12
150	252.4	163.2	50.48	67.36	32.64
75	78.6	84.6	15.72	83.08	16.92
-75	84.6	0.0	16.92	100.00	0.00

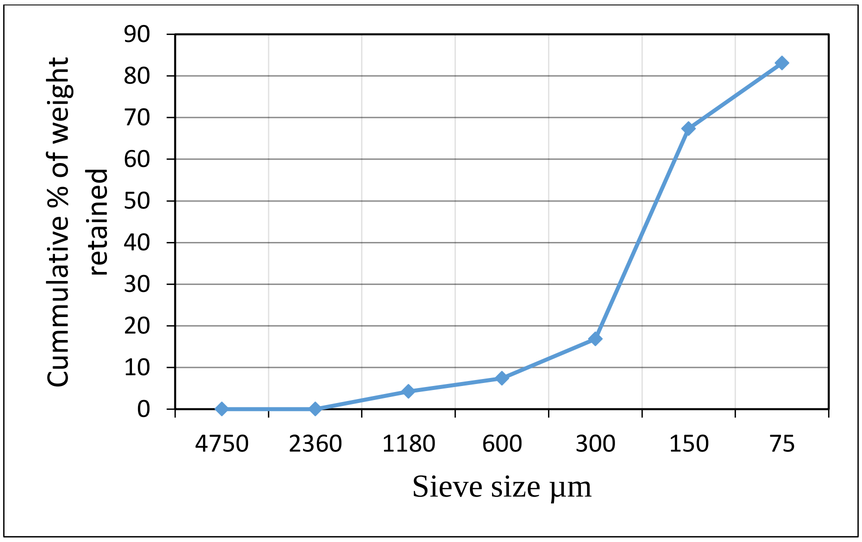


Fig. 6.10 Cumulative percentage retained vs. sieve size for Sample-9

6.4 SAMPLING

Table 6.12 gives the details of the sampling carried out using coning and quartering on all the nine different samples. From each material of 2000 gm, around 125 gm of sample was collected for further analysis (chemical analysis by conventional method and SEM method). Three trials were carried out on each type of sample.

Table 6.12 Details of Sampling (Coning and Quartering Technique)

Trails	**Iteration -1**	**Iteration - 2**	**Iteration - 3**	**Iteration - 4**
Sample - 1				
Trail1	1000.8	500.8	250.5	125.4
Trail2	1000.2	500.9	250.2	125.8
Trail3	999.6	500.5	249.8	124.5
Sample - 2				
Trail1	1001.8	500.2	249.5	125.4
Trail2	999.8	499.5	250.5	124.5
Trail3	1000.5	499.8	251	125.9
Sample - 3				
Trail1	999.6	501.5	249.4	125.1
Trail2	1000.9	500.4	250.2	125.9
Trail3	1001.5	499.2	250.5	124.5
Sample - 4				
Trail1	1000.5	500.5	250.1	125.5
Trail2	999.8	500.8	250.5	124.2
Trail3	1000.6	499.5	249.4	123.9
Sample - 5				
Trail1	1000.9	500.5	249.5	125.5
Trail2	999.8	499.8	250.5	124.8
Trail3	999.5	500.8	250.8	124.7
Sample - 6				
Trail1	1010.0	506.0	256.4	126.2
Trail2	1002.0	500.8	248.5	124.4
Trail3	1008.0	502.0	248.6	125.4
Sample - 7				
Trail1	999.0	502.1	249.8	126.1
Trail2	999.5	499.5	250.9	125.2
Trail3	1000.8	500.8	250.2	124.7
Sample - 8				
Trail1	1001.0	494.4	246.4	124.2
Trail2	1002.0	501.2	253.0	125.5
Trail3	1000.5	500.8	251.0	124.8
Sample - 9				
Trail1	1002.5	501.0	249.5	126.0
Trail2	998.4	499.5	250.9	124.2
Trail3	1001.8	502.8	252.5	125.5

6.5 CHEMICAL ANALYSIS

6.5.1 Conventional Method

Table 6.13 gives the results of chemical analysis which was carried out by digestion method, photometric method and atomic absorption method. As indicated in the Table 6.13, at locations 6, 7 and 8 the Fe_2O_3 content is above 30 %. Hence, these three locations were ignored since this material could be used in near future as ore by upgrading or blending it with high grade ore. Sample locations at 1, 2, 3, 4, 5 and 9 were only considered for this study, as the percentage of Fe_2O_3 was too low and it is felt that this material will be still considered as waste in the years to come. As can be seen from Figure 6.11, the major chemical composition of the iron ore waste are; SiO_2, Al_2O_3 and Fe_2O_3.

Table 6.13 Chemical analysis of iron ore waste (mass %)

Sample Location No.	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
S1	0.0332	0.1900	22.270	40.700	0.0542	4.7900	1.20	22.930
S2	0.8850	0.1040	27.530	33.015	0.0788	3.6490	0.94	27.240
S3	0.0664	0.0563	34.000	40.240	0.0602	5.5390	1.56	15.200
S4	0.0553	0.7980	21.420	50.802	0.0482	6.8457	0.55	20.181
S5	0.0442	0.3750	25.321	50.133	0.0301	3.3206	0.85	15.379
S6	0.1494	0.0213	22.976	21.196	0.0723	5.3977	0.70	58.880
S7	0.1217	0.0930	30.450	38.800	0.1385	6.5219	0.65	32.080
S8	0.3653	0.3046	13.900	29.450	0.0498	2.0760	0.36	48.100
S9	0.1328	0.2732	16.400	41.700	0.1385	7.1140	1.50	29.450

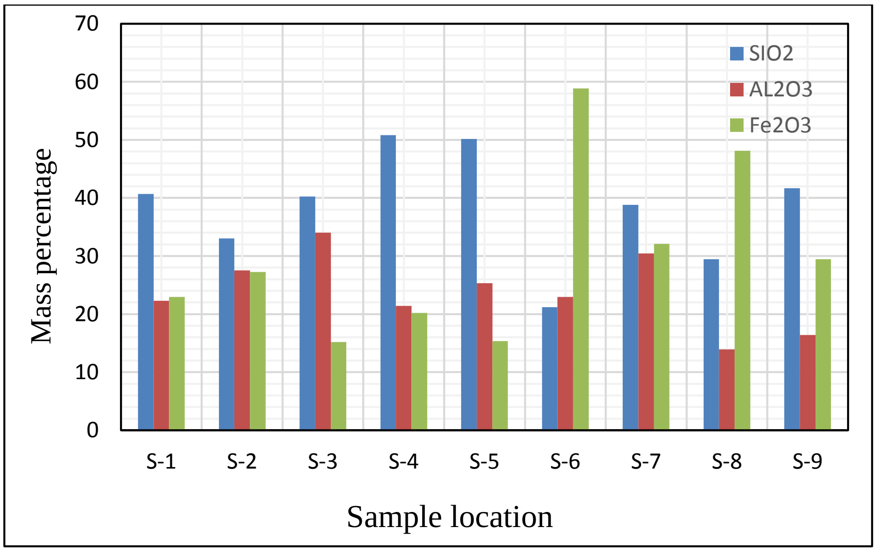
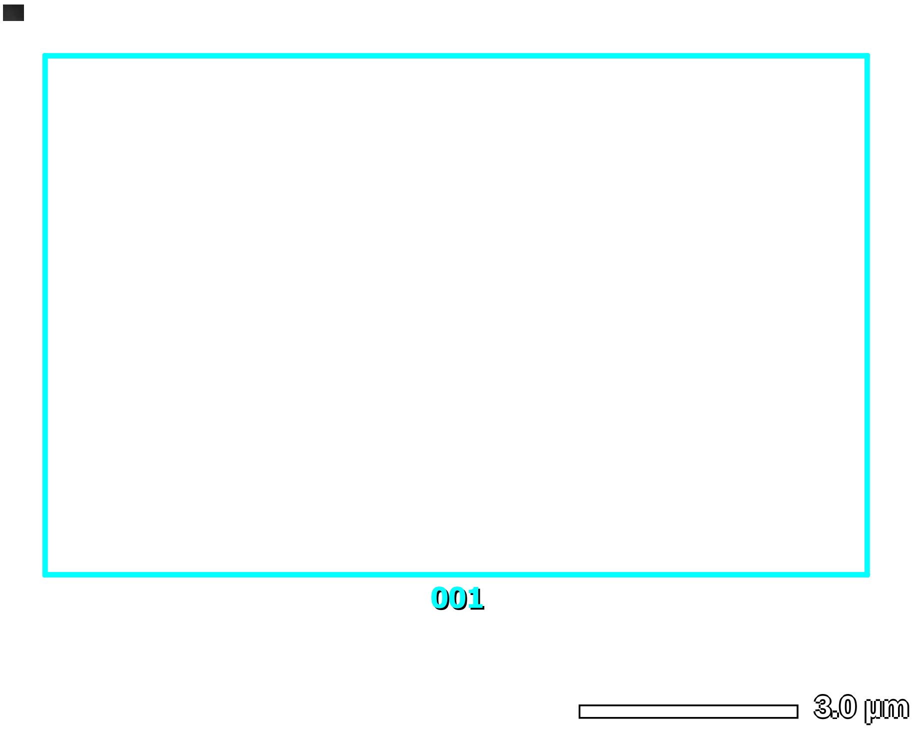


Fig. 6.11 Mass percentage of S_iO_2, Al_2O_3 and Fe_2O_3



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Instrument      :
Volt            : 20.00 kV
Mag             : x 10,000
Date            : 2013/12/11
Pixel           : 640 x 480
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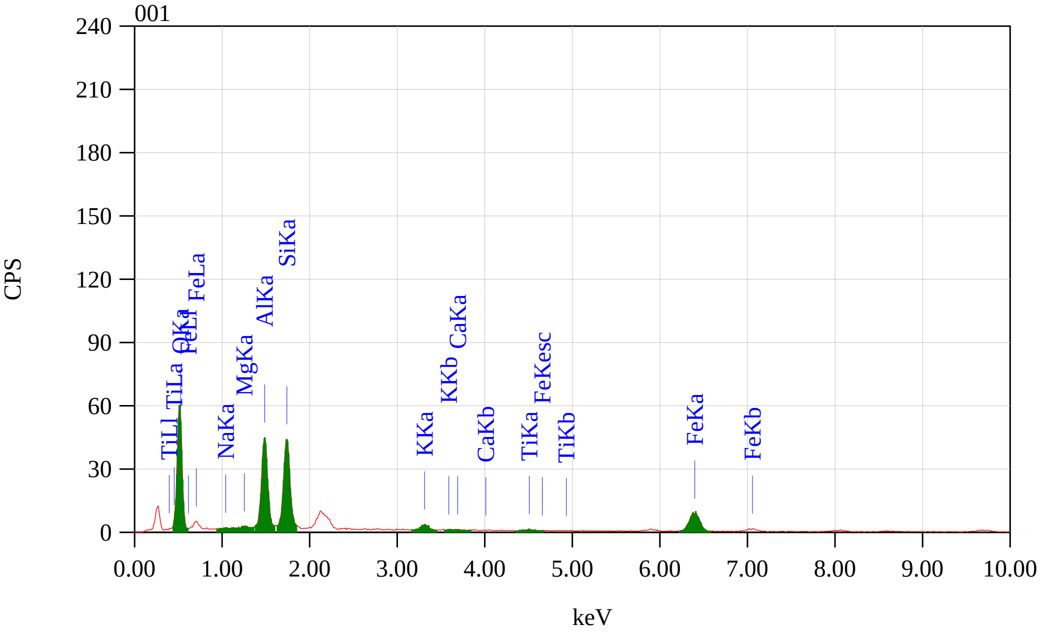

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Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 68.27 sec
Live Time     : 50.00 sec
Dead Time     : 25 %
Counting Rate: 2817 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2581
Total Oxide : 24.0
Element         (keV)    mass%  Error%     Mol%  Compound     mass%  Cation          K
 O                       44.04
Na K            1.041     0.18    0.31     0.28  Na2O          0.24    0.07     0.2534
Mg K            1.253     0.45    0.29     1.34  MgO           0.74    0.16     0.5858
Al K            1.486    17.96    0.29    24.29  Al2O3        33.94    5.81    28.7506
Si K            1.739    19.83    0.39    51.53  SiO2         42.43    6.16    31.1501
 K K            3.312     1.50    0.22     1.40  K2O           1.81    0.34     3.5630

Ca K            3.690     0.19    0.30     0.34  CaO           0.26    0.04     0.4735
Ti K            4.508     0.49    0.43     0.75  TiO2          0.82    0.09     1.0828
Fe K            6.398    15.35    0.59    20.06  FeO          19.75    2.40    34.1407
Total                   100.00           100.00              100.00   15.05
```

Fig. 6.12 SEM results for Sample-1

6.5.2 SEM Method

Figure 6.12 shows a sample image (Sample – 1) of analysis carried out using Scanning Electron Microscope (SEM) for analyzing the morphological structure of the materials. Here, the images were taken with different magnification at various points. The study of different phases of metals was identified by Energy Dispersive X-ray Spectroscopy (EDAX). The results of Elemental Properties (mass %) using Scanning Electron Microscope are given in Table 6.14. The details of other images on various other samples are given in ANNEXURE – I.

Table 6.14 Elemental Properties (mass %) using Scanning Electron Microscope

Sample No.	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO
1	0.24	0.74	33.94	42.43	1.81	0.26	0.82	19.75
2	0.11	0.08	31.02	35.55	0.88	0.11	0.69	31.57
3	0.19	0.92	33.94	47.06	5.27	0.03	1.43	11.18
4	0.30	0.06	26.35	54.94	0.24	0.11	0.35	17.64
5	0.23	1.51	30.65	45.26	7.02	ND	0.66	14.56
6	0.19	0.26	18.75	19.25	0.21	0.34	0.51	60.49
7	0.57	0.56	29.99	36.49	0.57	0.07	0.47	31.29
8	0.07	0.41	24.90	26.45	0.36	0.23	0.24	47.33
9	0.06	1.10	27.45	39.55	1.99	1.04	1.37	27.52

From Table 6.14 it is seen that different oxides with the majority having SiO_2, Al_2O_3 and FeO are found in the samples as shown by the conventional method too. A significant mass percentage of K_2O was found in different samples. Further traces of Na_2O, MgO, CaO and TiO_2 were also found in the sample. The mass percentage of SiO_2, Al_2O_3 and FeO of all the nine samples are shown in Figure 6.13. As can be seen, the results of SEM analysis are almost in line with that of conventional method with minor deviation.

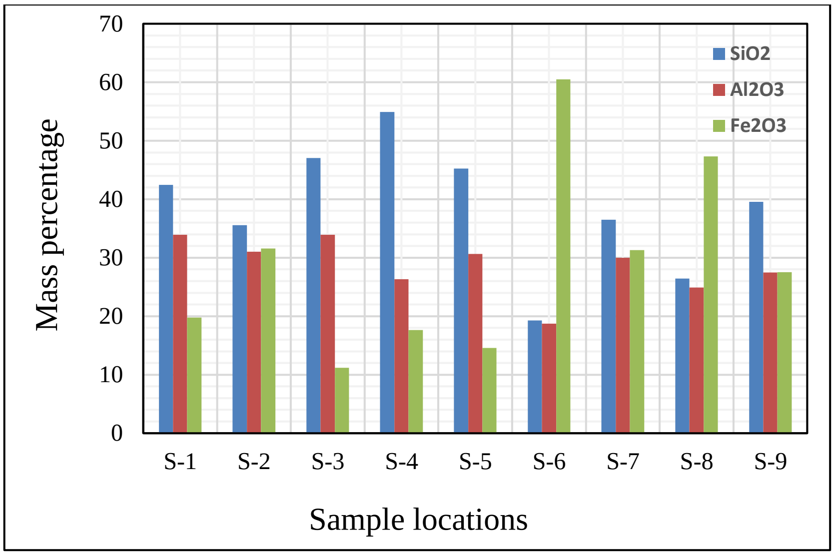

Fig. 6.13 Mass percentage of S_iO_2, Al_2O_3 and FeO at various sample locations

6.6 RESULTS OF COMPRESSIVE STRENGTH

6.6.1 Seelu Kola (SK) Area (Sample – 1)

The results of the compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 1 are given in Table 6.15 to Table 6.20.

Based on the results obtained from Table 6.15 to Table 6.20, the variation in compressive strength with respect to number of curing days was analysed.

6.6.1.1 Sample – 1 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.14 for Sample-1, with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 11.69 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. It is clear from the Figure 6.14 that the minimum required compressive strength as per IS standards of 3.5 MPa, is achieved with cement of 10 % with 21 days of curing and above. However, for bricks with cement content of 5 %, it was observed that the compressive strength is below 1 MPa. Because of its lower strength and fragile in nature, further studies on other samples with 5 % cement content was not considered in this investigation.

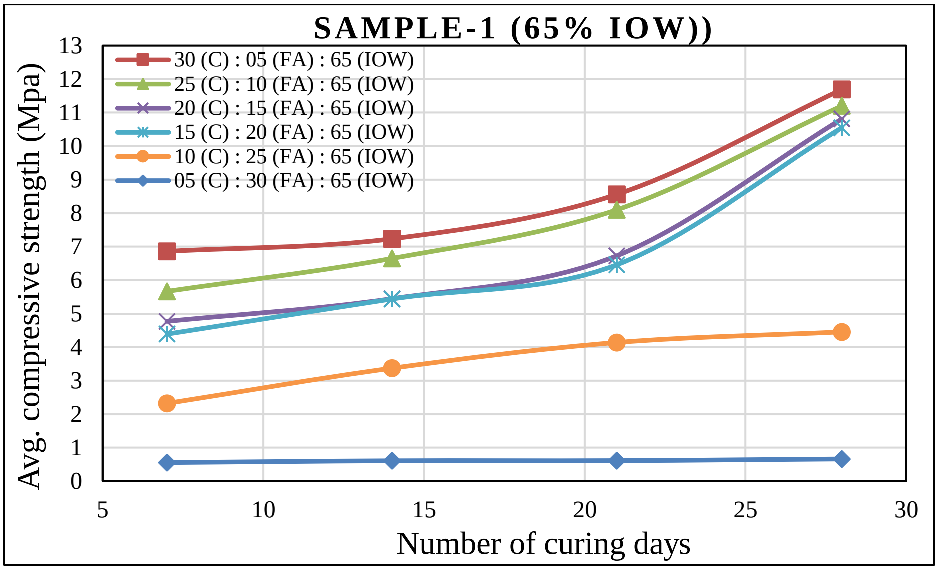

Fig. 6.14 Compressive strength vs. number of curing days

6.6.1.2 Sample – 1 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-1, with 70 % iron ore waste is shown in Figure 6.15 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength 11.59 MPa was obtained with 30 % cement and 70 % IOW for 28 day of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 21days and above. It was also observed that, with 30 % cement, the increase in compressive strength from 21 to 28 days of curing is 0.352 MPa only.

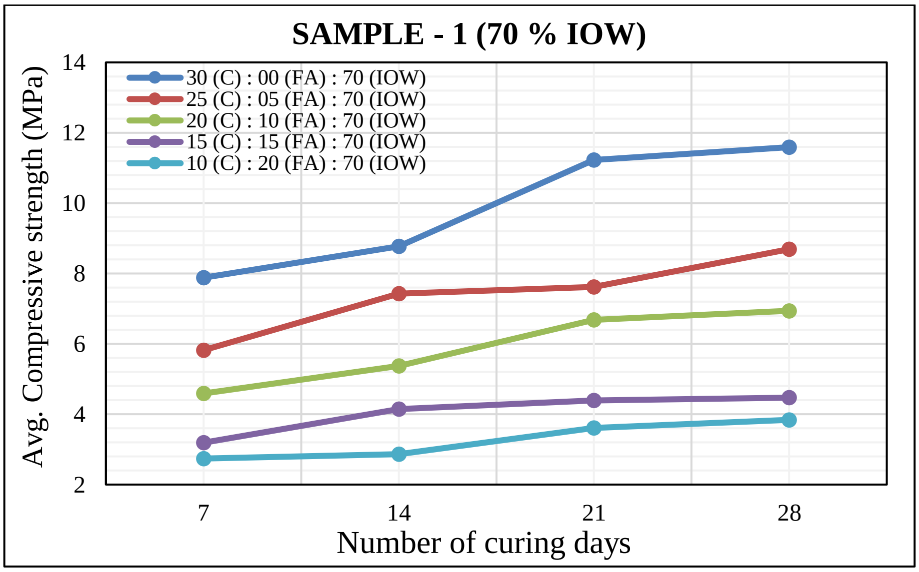

Fig. 6.15 Compressive strength vs. number of curing days

6.6.1.3 Sample – 1 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.16 for Sample-1, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 1 5% with 5 % interval. The maximum compressive strength 11.95 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 21 days of curing and above. It was also observed that, with 25 % cement, there was a gradual increase in the compressive strength: 11.63, 11.68, 11.81 and 11.95 MPa for 7, 14, 21 and 28 days of curing respectively.

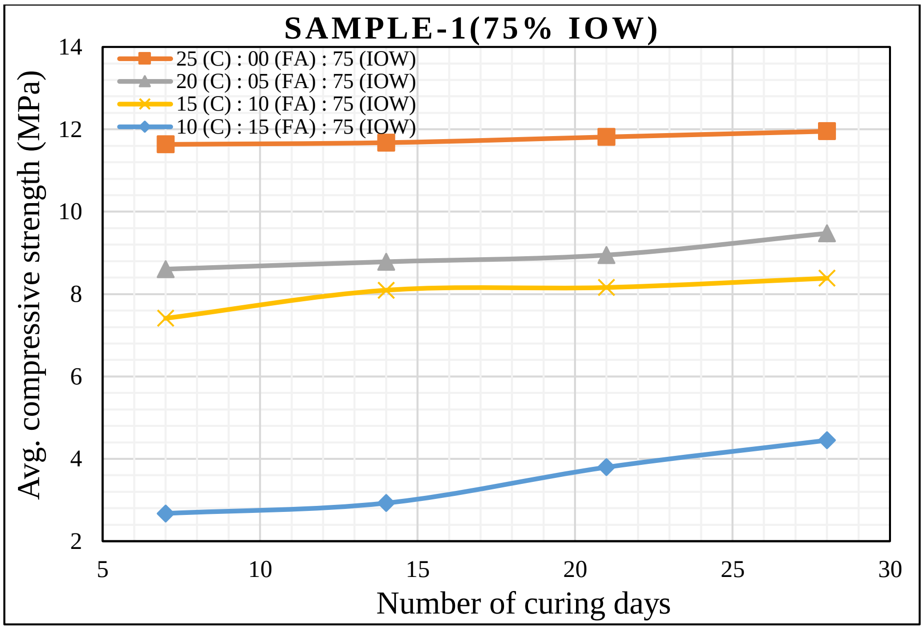

Fig. 6.16 Compressive strength vs number of curing days

6.6.1.4 Sample – 1 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Figure 6.17 for Sample-1, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 5.79 MPa was obtained with 20 % cement and 80 % IOW for 28 day of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 28 days of curing and for cement of 15% with and above 14 days of curing. It was also observed that, with increase in IOW and decrease in cement percentage, the compressive strength also decreases. Hence, to achieve the minimum required compressive strength, more number of curing period is required.

6.6.1.5 Sample – 1 with 85 % IOW

A plot of compressive strength of the bricks vs number of curing days is shown in Figure 6.18 for Sample-1, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength 5.32 MPa was obtained with 15 % cement for 28 days of curing. With 21 days of curing, the compressive strength observed was 3.45 MPa which is very close to the minimum required strength. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 28 days of curing period. It was also observed that with 15 % cement, the maximum strength was 5.32 MPa for 28 days of curing, whereas with 10 % cement, the strength observed was 3.53 MPa for 28 days of curing. This may be due to presence of more fly ash in the case of 10 % cement bricks.

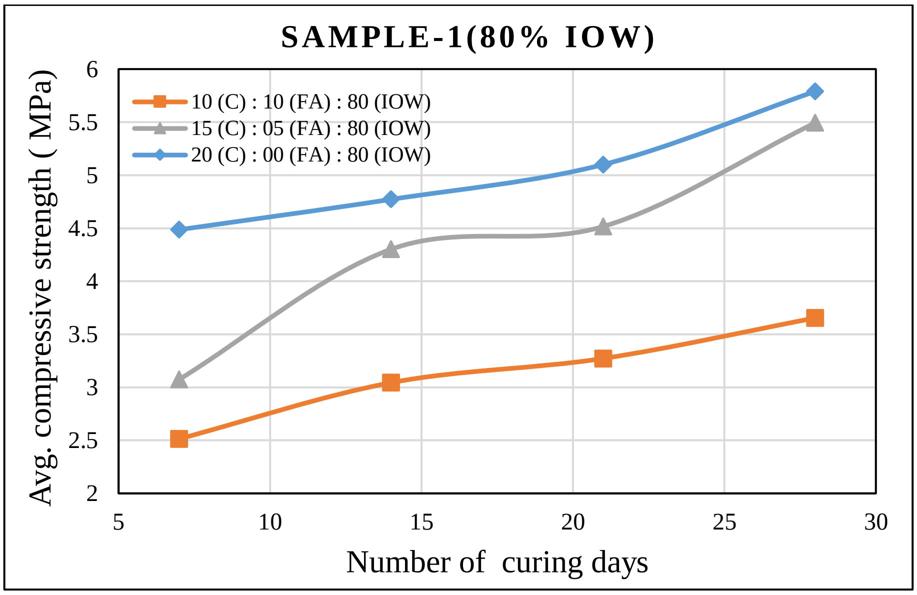

Fig. 6.17 Compressive strength vs. number of curing days

6.6.1.6 Sample – 1 with 90 % IOW

Figure 6.19 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-1with 10 % cement, 0 % fly-ash and 90 % iron ore waste. It was observed that, there is increase in strength with respect to number of curing days. The required compressive strength was obtained with 28 days of curing period.

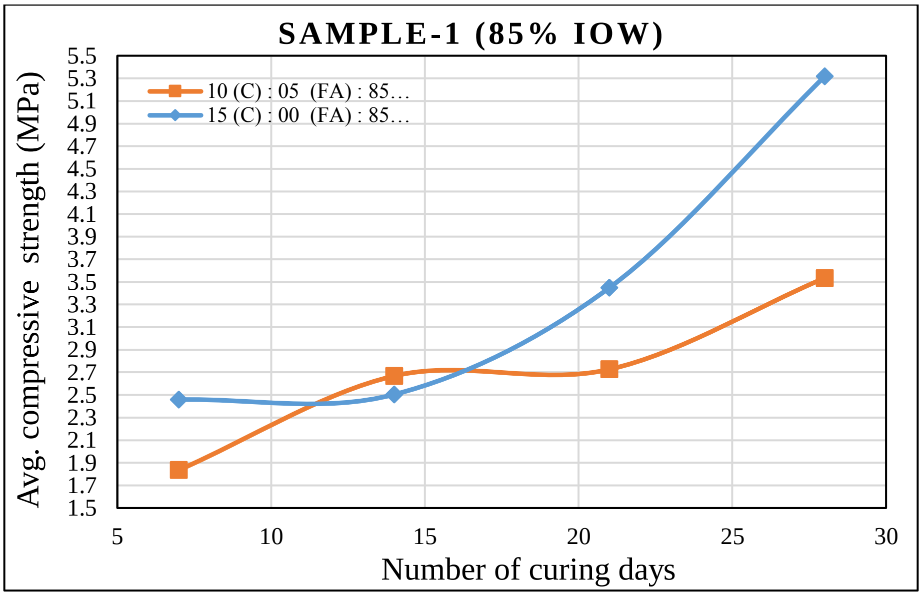

Fig. 6.18 Compressive strength vs. number of curing days

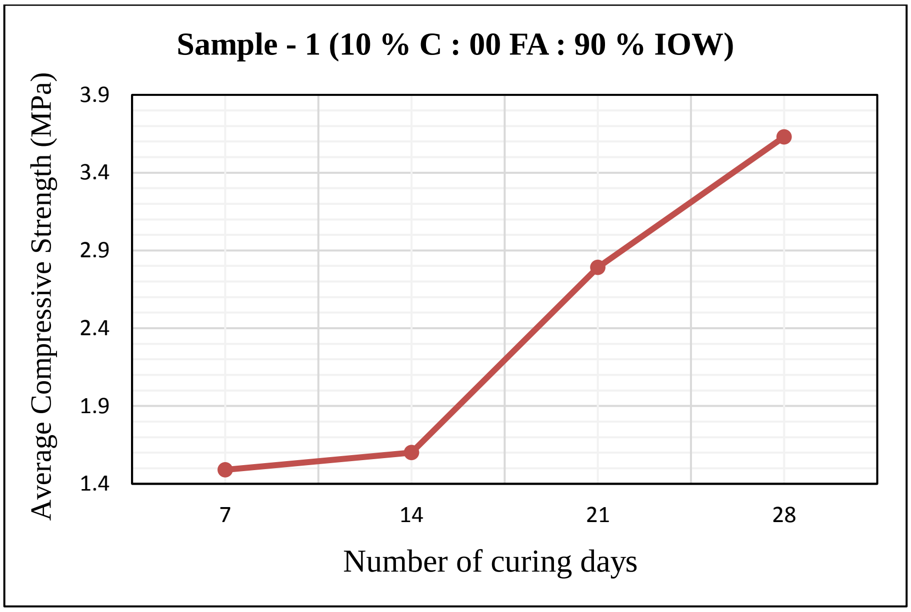

Fig. 6.19 Compressive strength vs. number of curing days

Results from Table 6.15 to Table 6.20, and Figure 6.14 to Figure 6.19 on compressive strength of bricks reveal that, the minimum required compressive strength of 3.5 MPa is achieved with 10 % cement with 28 days of curing

Table 6.15 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 1 with 65 % IOW

	Cement (C) : Fly ash (FA) : Iron ore waste (IOW)															
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	6.90	7.50	8.90	12.00	5.86	6.50	7.85	11.20	4.60	5.60	6.90	10.90	4.00	5.40	6.50	10.50
S2	6.57	7.00	8.45	11.46	5.47	6.53	7.90	11.25	4.65	5.40	6.59	10.79	4.10	5.49	6.45	10.65
S3	7.00	7.45	8.60	11.53	5.75	6.44	8.00	11.10	4.81	5.36	6.60	10.75	4.70	5.60	6.40	10.45
S4	6.89	6.98	8.00	11.60	5.60	6.87	8.25	11.15	5.00	5.42	6.75	10.76	4.55	5.25	6.46	10.55
S5	6.94	7.24	8.85	11.85	5.65	6.90	8.50	11.30	4.79	5.45	6.80	10.85	4.60	5.45	6.49	10.60
Average compressive strength (MPa)	6.86	7.23	8.56	11.69	5.67	6.65	8.10	11.20	4.77	5.45	6.73	10.81	4.39	5.44	6.46	10.55

Contd.

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)								
Proportion of material	10:25:65 (C:FA:IOW) (E)				05:30:65 (C:FA:IOW) (F)			
No. of days for curing bricks	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)							
S1	2.30	3.40	4.10	4.50	0.56	0.59	0.62	0.65
S2	2.28	3.20	4.20	4.44	0.58	0.65	0.63	0.70
S3	2.38	3.50	4.25	4.46	0.55	0.60	0.62	0.68
S4	2.36	3.46	4.00	4.48	0.54	0.58	0.60	0.64
S5	2.29	3.30	4.15	4.40	0.56	0.63	0.60	0.65
Average compressive strength (MPa)	2.32	3.37	4.14	4.46	0.56	0.61	0.61	0.66

Table 6.16 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample-1 with 70 % IOW

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)																			
S1	8.58	8.82	11.30	11.52	5.87	7.55	7.54	8.67	4.33	5.37	6.38	6.96	3.39	4.14	4.53	4.37	2.90	2.95	3.50	3.79
S2	7.50	8.71	11.25	11.43	5.95	7.38	7.72	8.65	4.74	5.45	6.92	6.85	3.08	4.06	4.27	4.58	2.63	2.84	3.53	3.85
S3	7.97	8.77	11.14	11.75	5.71	7.29	7.61	8.74	4.63	5.25	6.67	7.12	3.21	4.21	4.40	4.44	2.79	2.80	3.60	3.80
S4	7.60	8.75	11.20	11.58	5.80	7.45	7.59	8.70	4.70	5.36	6.70	6.90	3.17	4.18	4.35	4.50	2.75	2.85	3.75	3.88
S5	7.75	8.80	11.28	11.65	5.78	7.50	7.65	8.69	4.55	5.40	6.75	6.88	3.10	4.15	4.40	4.48	2.65	2.84	3.65	3.90
Average compressive strength (MPa)	7.88	8.77	11.23	11.59	5.82	7.43	7.62	8.69	4.59	5.37	6.68	6.94	3.19	4.15	4.39	4.47	2.74	2.86	3.61	3.84

Table 6.17 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample-1 with 75 % IOW

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	11.57	11.56	11.77	11.97	8.66	8.72	8.98	9.38	7.51	8.04	8.11	8.39	2.71	2.97	3.96	4.61
S2	11.70	11.67	11.85	11.88	8.67	8.86	8.96	9.51	7.42	7.91	8.25	8.46	2.63	2.88	3.68	4.30
S3	11.67	11.77	11.84	12.01	8.52	8.78	8.91	9.56	7.31	8.07	8.10	8.32	2.68	2.90	3.72	4.45
S4	11.63	11.68	11.82	11.92	8.58	8.80	8.94	9.40	7.38	8.00	8.18	8.40	2.65	2.96	3.78	4.50
S5	11.60	11.70	11.79	11.98	8.60	8.76	8.95	9.52	7.44	8.45	8.16	8.35	2.70	2.92	3.84	4.39
Average compressive strength (MPa)	11.63	11.68	11.81	11.95	8.61	8.78	8.95	9.47	7.41	8.09	8.16	8.38	2.67	2.93	3.80	4.45

Table 6.18 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample-1 with 80 % IOW

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	4.45	4.84	5.05	5.85	3.05	4.33	4.45	5.57	2.47	2.99	3.31	3.62
S2	4.54	4.67	5.14	5.89	2.97	4.29	4.61	5.50	2.49	3.05	3.22	3.65
S3	4.48	4.75	5.12	5.86	3.00	4.30	4.50	5.48	2.57	3.12	3.28	3.69
S4	4.50	4.78	5.09	5.60	3.20	4.27	4.58	5.52	2.54	2.96	3.25	3.67
S5	4.46	4.82	5.10	5.75	3.15	4.32	4.44	5.40	2.50	3.10	3.30	3.64
Average compressive strength (MPa)	4.49	4.77	5.10	5.79	3.07	4.30	4.52	5.49	2.51	3.04	3.27	3.65

Table 6.19 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample-1 with 85 % IOW

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing bricks	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)							
S1	2.40	2.47	3.44	5.36	1.85	2.64	2.87	3.58
S2	2.44	2.54	3.50	5.24	1.87	2.69	2.85	3.60
S3	2.49	2.49	3.46	5.28	1.84	2.65	2.84	3.64
S4	2.50	2.5	3.35	5.30	1.82	2.70	2.76	3.66
S5	2.46	2.52	3.49	5.40	1.80	2.66	2.70	3.69
Average compressive strength (MPa)	2.46	2.50	3.45	5.32	1.84	2.67	2.80	3.63

Table 6.20 Compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample-1 with 90 % IOW

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing bricks	7	14	21	28
Brick sample	Compressive Strength (MPa)			
S1	1.59	1.65	2.87	3.58
S2	1.49	1.54	2.85	3.60
S3	1.40	1.56	2.84	3.64
S4	1.52	1.60	2.67	3.66
S5	1.46	1.66	2.70	3.69
Average compressive strength (MPa)	1.49	1.60	2.79	3.63

6.6.2 Kaniga Marada Kola (KMK) Area - (Sample – 2)

The results of average compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 2 are given in Table 6.21. The detailed results of compressive strength for each individual bricks for all the mix ratios for Sample – 2 are given in ANNEXURE-II.

Based on the results obtained from Table 6.21, the variation in compressive strength with respect to number of curing days was analysed.

6.6.2.1 Sample – 2 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.20 for Sample-2, with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 11.05 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. It is clear from the Fig. 6.20 that the minimum required compressive strength as per IS standards of 3.5 MPa, is achieved with cement of 10 % with 21 days of curing and above. From Figure 6.20 a significant change in compressive strength from 14 days of curing to 21 days of curing is seen.

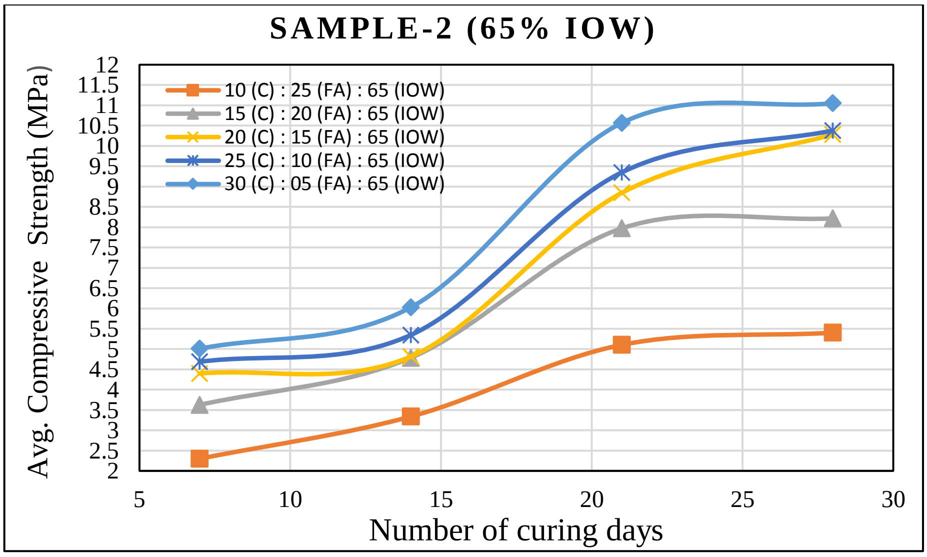

Fig. 6.20 Compressive strength vs. number of curing days

6.6.2.2 Sample – 2 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-2, with 70 % iron ore waste is shown in Figure 6.21 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength 12.31 MPa was obtained with 30 % cement and 70 % IOW for 28 day of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 14 and above. It was also observed that, with 30 % cement, the increase in compressive strength from 21 to 28 days of curing is 0.54 MPa only.

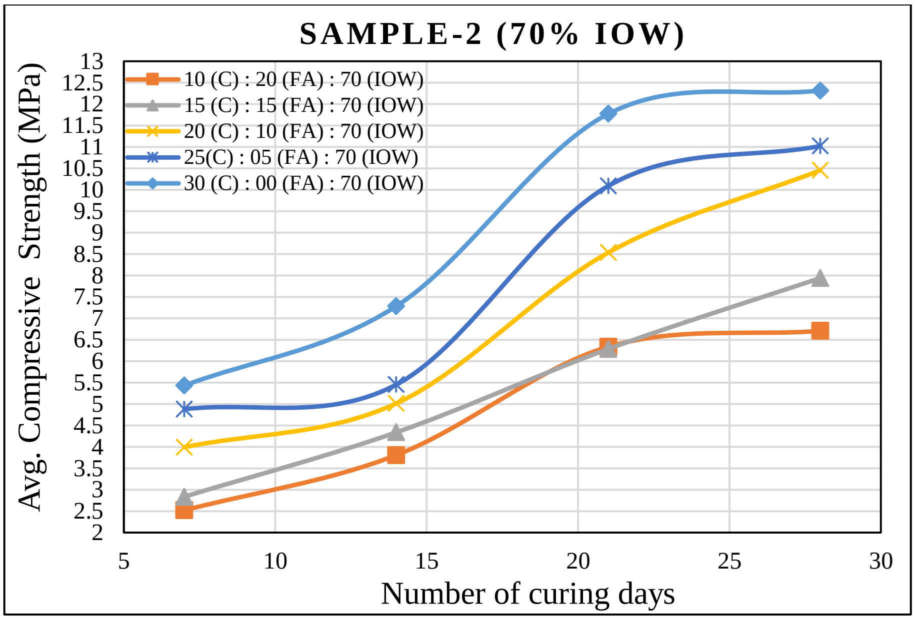

Fig. 6.21 Compressive strength vs. number of curing days

6.6.2.3 Sample – 2 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.22 for Sample-2, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 15 % with 5 % interval. The maximum compressive strength 10.05 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 14 days of curing and above. It was also observed that, for all the mix ratios, there is a little increase in compressive strength from 21 days of curing to 28 days of curing. There is a significant change in compressive strength of the bricks with 7 days of curing, 14 days of curing and 21 days of curing.

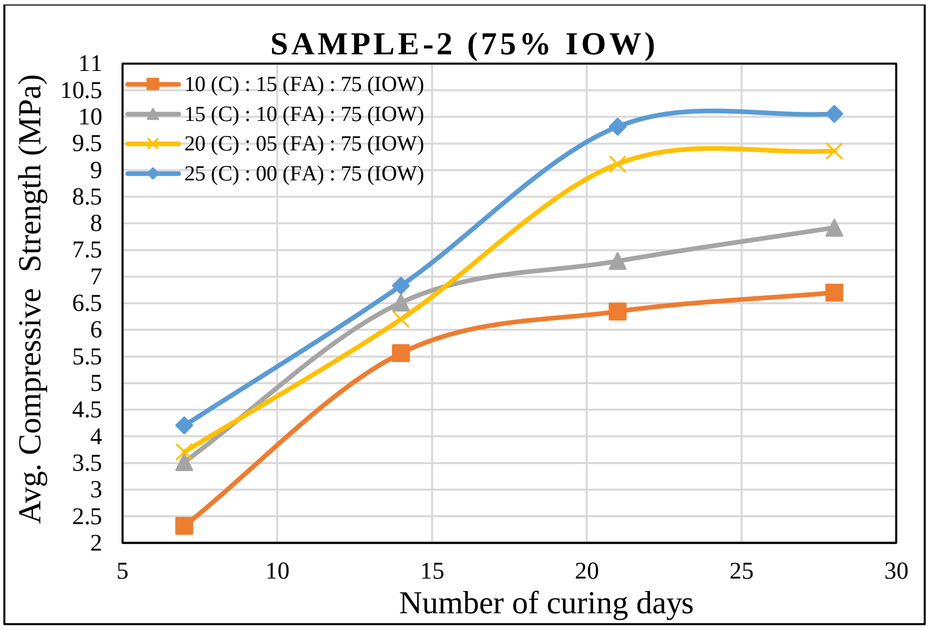

Fig. 6.22 Compressive strength vs. number of curing days

6.6.2.4 Sample – 2 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Figure 6.23 for Sample-2, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 8.95 MPa was obtained with 20 % cement and 80 % IOW for 28 day of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing and above. It was also observed that, with increase in IOW and decrease in cement percentage, the compressive strength also decreases. Hence, to achieve the minimum required compressive strength, more number of curing period is required. However, with 15 % cement ratio the increase in compressive strength from 21 days of curing to 28 days of curing is only 0.128 MPa. Hence, 21 days of curing may be adopted for bricks with 15 % cement content.

6.6.2.5 Sample – 2 with 85 % IOW

A plot of compressive strength of the bricks vs. number of curing days is shown in Figure 6.24 for Sample-2, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength 6.55 MPa was obtained with 15 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing period. It was also observed that with 15 % cement, the maximum strength was 6.55 MPa for 28 days of curing, whereas with 10 % cement, the strength observed was 5.46 MPa for 28 days of curing. This may be due to presence of more fly ash in the case of 10 % cement bricks. A significant change in compressive strength was observed from 7 days of curing to 14 days of curing.

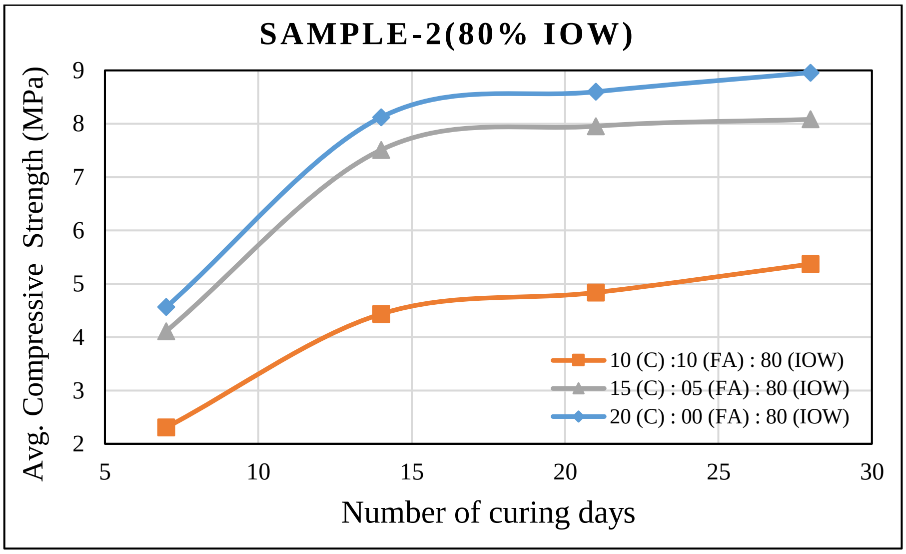

Fig. 6.23 Compressive strength vs. number of curing days

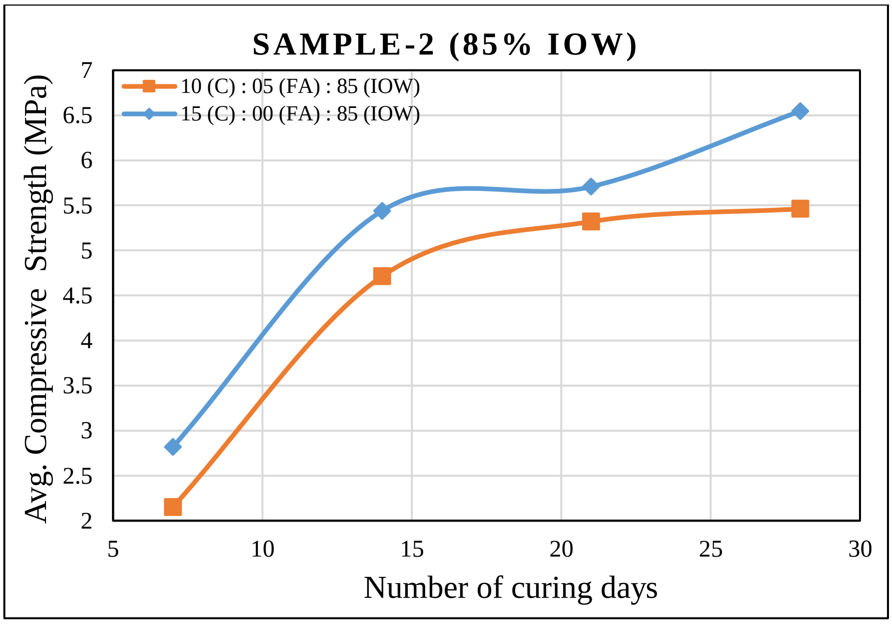

Fig. 6.24 Compressive strength vs. number of curing days

6.6.2.6 Sample – 2 with 90 % IOW

Figure 6.25 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-2 with 10 % cement, 0 % fly-ash and 90 % iron ore waste. It was observed that, there is increase in strength with respect to number of curing days. The maximum compressive strength 4.15 MPa was obtained with 10 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing period and above. A significant increase in compressive strength of the order of 1.46 and 3.91 MPa for 7 days and14 days of curing respectively was observed. From the results it is clear that with 10 % cement, to achieve the required strength as per IS standards, 14 days of curing may be carried out.

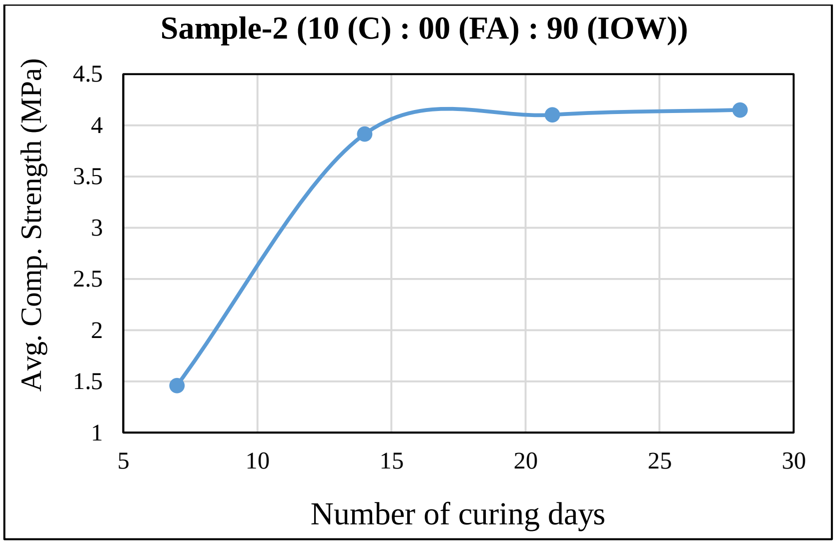

Fig. 6.25 Compressive strength vs. number of curing days

Table 6.21 Average compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 2

Cement(C):Fly ash(FA): Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	5.01	6.02	10.56	11.05	4.69	5.35	9.35	10.37	4.4	4.82	8.84	10.28	3.62	4.78	7.97	8.21	2.30	3.33	5.10	5.40
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
Average compressive strength (MPa)	5.43	7.28	11.77	12.31	4.87	5.45	10.08	11.01	3.99	5.01	8.53	10.45	2.83	4.33	6.28	7.93	2.51	3.80	6.33	6.70

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Cement(C):Fly ash(FA): Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	4.20	6.83	9.81	10.05	3.70	6.20	9.11	9.36	3.51	6.51	7.29	7.92	2.31	5.56	6.34	6.7
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)							
Average compressive strength (MPa)	4.56	8.12	8.6	8.95	4.11	7.51	7.95	8.08	2.30	4.43	4.83	5.37	---			
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				---							
Average compressive strength (MPa)	2.818	5.438	5.701	6.55	2.15	4.71	5.32	5.46	---							
Proportion of material	10:00:90 (C:FA:IOW) (A)				---											
Average compressive strength (MPa)	1.46	3.91	4.10	4.15	---											

6.6.3 Neeru Kola (NK) Area - (Sample – 3)

The results of average compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 3 are given in Table 6.22. The results of compressive strength for each individual bricks for all the mix ratios for Sample – 3 are given in ANNEXURE-1.

Based on the results obtained from Table 6.22, the variation in compressive strength with respect to number of curing days was analysed.

6.6.3.1 Sample – 3 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.26 for Sample-3 with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 16.49 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. It is clear from the Figure 6.26 that the minimum required compressive strength as per IS standards of 3.5 MPa, is achieved with cement of 10 %, 25 % of fly ash and 65 % of IOW with 7 days of curing. This may be due to presence of 25 % fly ash in the brick. From Figure 6.26 it was observed that there is almost uniform increase in strength with 7, 14, 21 and 28 days of curing. It was also observed that for all the mix ratio, the compressive strength of bricks are much above the minimum required strength for 7 day of curing only.

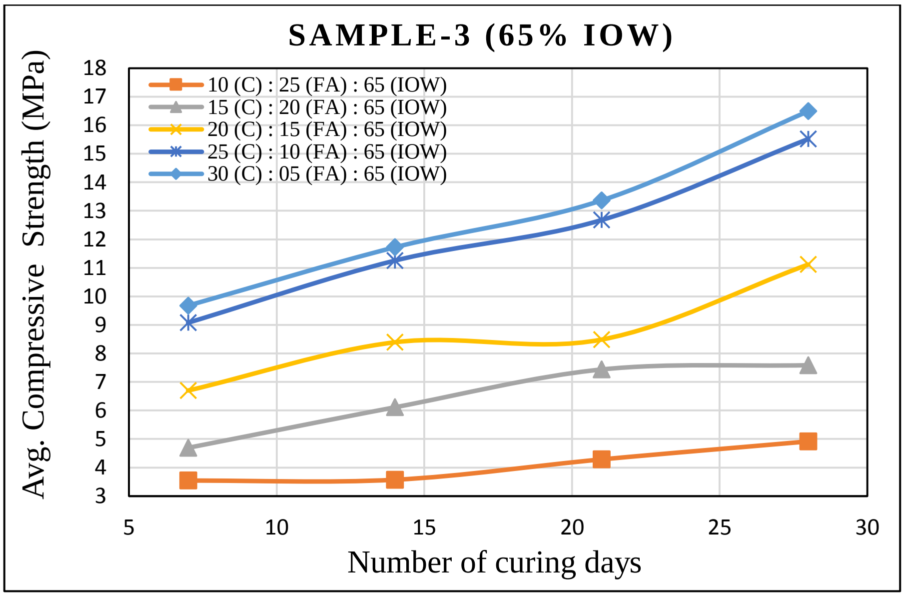

Fig. 6.26 Compressive strength vs. number of curing days

6.6.3.2 Sample – 3 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-3, with 70 % iron ore waste is shown in Figure 6.27 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength 14.41 MPa was obtained with 30 % cement and 70 % IOW for 28 day of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 14 days and above. It was also observed that, with 30 % cement, the increase in compressive strength from 7 to 14 days of curing is 0.5 MPa only.

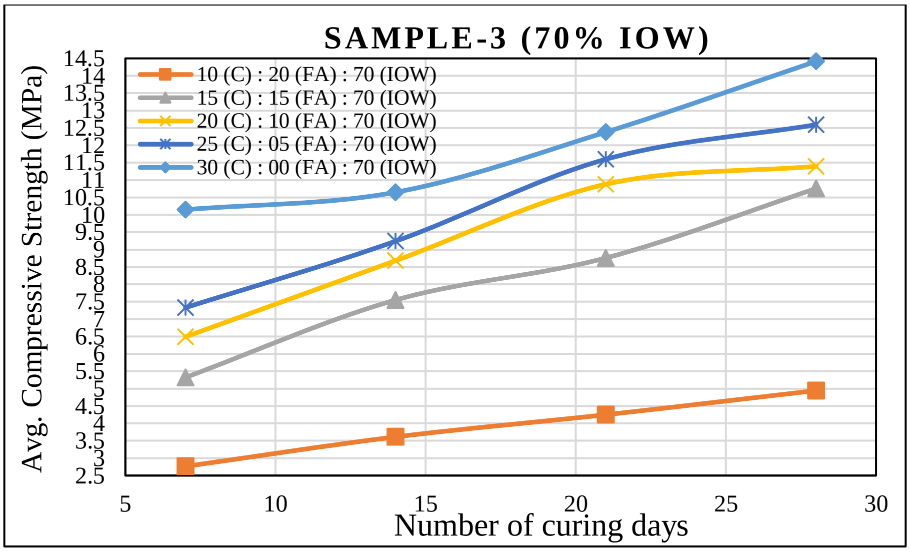

Fig. 6.27 Compressive strength vs. number of curing days

6.6.3.3 Sample – 3 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.28 for Sample-3, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 15% with 5 % interval. The maximum compressive strength 9.29 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 14 days of curing and above. It was also observed that, for mix ratio 15 % cement, 10 % fly ash and 75 % IOW there is a little increase in compressive strength from 21 days of curing to 28 days of curing. However in case of other mix ratios, there is a gradual change in compressive strength for 7 days of curing to 28 days of curing. This may be due to variation in cement and fly ash.

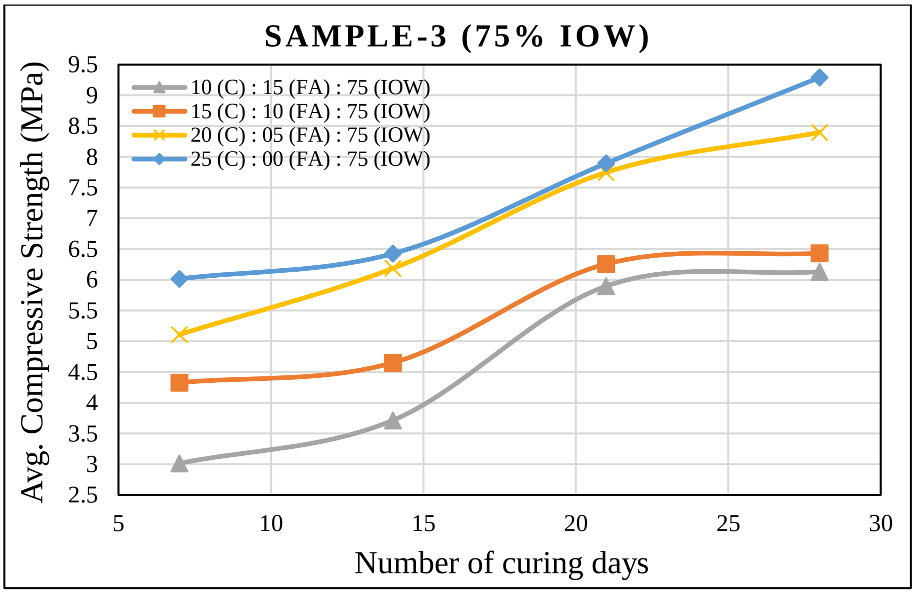

Fig. 6.28 Compressive strength vs. number of curing days

6.6.3.4 Sample – 3 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Figure 6.29 for Sample-3, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 7.75 MPa was obtained with 20 % cement and 80 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing and above. However, for all the mix ratios the increase in compressive strength is gradual and there is not much variation in strength with 7, 14, 21 and 28 days of curing. This may be due to 80 % of IOW. As we increase the ratio of IOW and decrease the cement percentage, the compressive strength also decreases.

6.6.3.5 Sample – 3 with 85 % IOW

A plot of compressive strength of the bricks vs. number of curing days is shown in Figure 6.30 for Sample-3, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength 5.87 MPa was obtained with 15 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 7 days of curing period. It was also observed that with 15 % cement, the maximum strength was 5.87 MPa for 28 days of curing, whereas with 10 % cement, the strength observed was 5.06 MPa for 28 days of curing. This may be due to presence of fly ash in the case of 10 % cement bricks. A gradual change in compressive strength was observed from 7, 14 21 and 28 days.

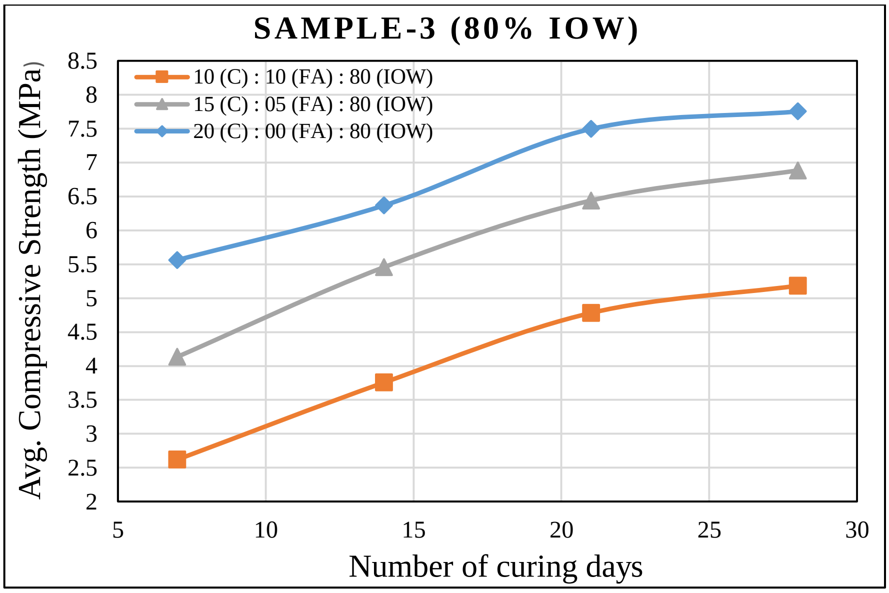

Fig. 6.29 Compressive strength vs. number of curing days

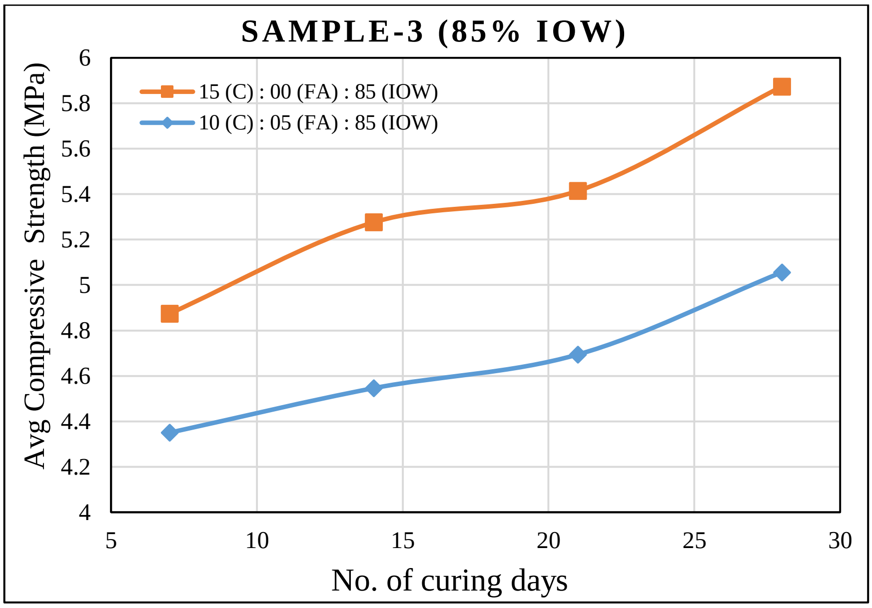

Fig. 6.30 Compressive strength vs. number of curing days

6.6.3.6 Sample – 3 with 90 % IOW

Figure 6.31 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-3 with 10 % cement, 0 % fly-ash and 90 % iron ore waste. It was observed that, there is increase in strength with respect to number of curing days. The maximum compressive strength 4.16 MPa was obtained with 10 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 21 days of curing period and above. However, with 10 % cement and 14 days of curing the compressive strength observed was 3.40 MPa, which is very close to minimum required compressive strength.

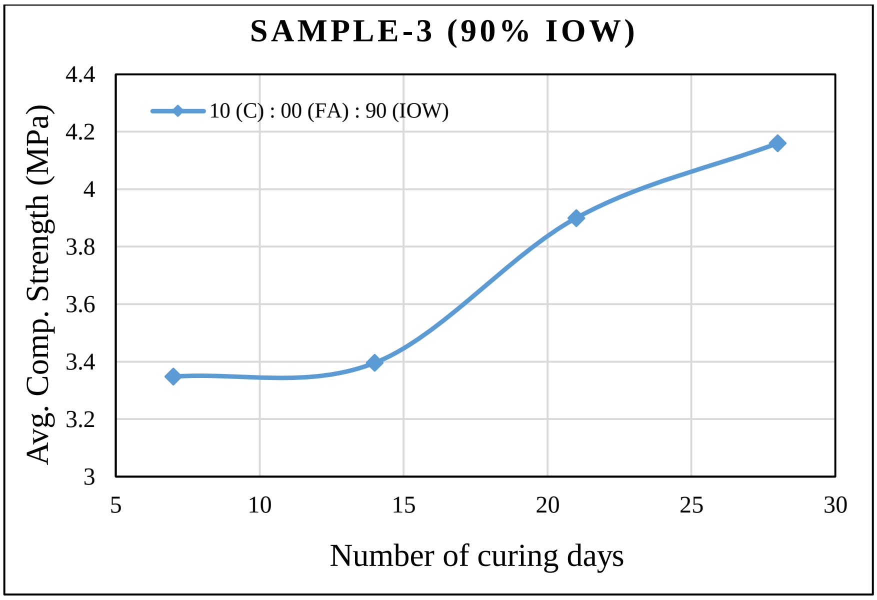

Fig. 6.31 Compressive strength vs. number of curing days

Table 6.22 Average compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 3

Cement(C):Fly ash(FA): Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	9.68	11.72	13.36	16.49	9.078	11.25	12.68	15.52	6.70	8.39	8.49	11.12	4.69	6.11	7.44	7.59	3.54	3.57	4.29	4.92
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
Average compressive strength (MPa)	10.15	10.65	12.38	14.41	7.33	9.24	11.60	12.59	6.49	8.68	10.88	11.40	5.32	7.55	8.76	10.75	2.76	3.61	4.25	4.94

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Cement(C):Fly ash(FA): Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	6.02	6.43	7.70	9.29	5.11	6.19	7.75	8.40	4.33	4.65	6.26	6.43	3.01	3.71	5.90	6.13
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)							
Average compressive strength (MPa)	5.56	6.37	7.50	7.75	4.13	5.46	6.44	6.88	2.62	3.76	4.78	5.18	---			
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				---							
Average compressive strength (MPa)	4.87	5.28	5.41	5.87	4.35	4.55	4.69	5.06	---							
Proportion of material	10:00:90 (C:FA:IOW) (A)				---											
Average compressive strength (MPa)	3.35	3.40	3.90	4.16	---											

6.6.4 Ankamnal Area - (Sample – 4)

The results of average compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 4 are given in Table 6.23. The results of compressive strength for each individual bricks for all the mix ratios for sample – 4 are given in ANNEXURE-1.

Based on the results obtained from Table 6.23, the variation in compressive strength with respect to number of curing days was analysed.

6.6.4.1 Sample – 4 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.32 for Sample-4, with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 17.09 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. The minimum required compressive strength as per IS Standards of 3.5 MPa is achieved with cement of 10 %, 25 % of fly ash and 65 % of IOW with 28 days of curing. From Figure 6.32 it was observed that with 30 % cement, there is significant change in strength from 21 days to 28 days of curing, i.e. 8.02 MPa to 17.09 MPa respectively. Whereas, there is not much variation in strength when compared to 25 % cement content brick and 20 % cement brick with 28 days of curing.

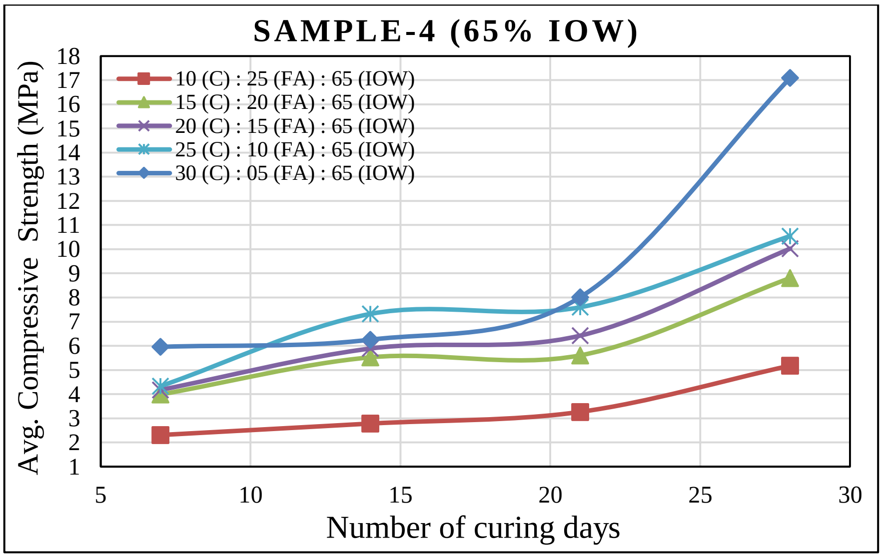

Fig. 6.32 Compressive strength vs. number of curing days

6.6.4.2 Sample – 4 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-4, with 70 % iron ore waste is shown in Figure 6.33 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength of 18.69 MPa was obtained with 30 % cement and 70 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 7 days and above. It was also observed that, with 30 % cement, the increase in compressive strength from 7 to 14 days of curing is 0.082 MPa only. This trend was observed with all other mix ratios also. It was further observed that there is significant change in strength from 21 days of curing to 28 days of curing for all the mix ratios.

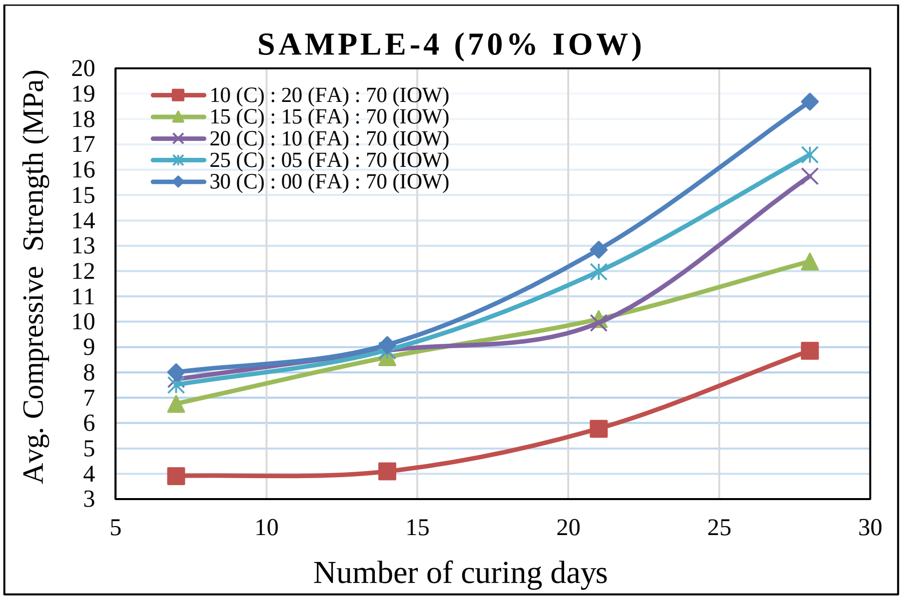

Fig. 6.33 Compressive strength vs. number of curing days

6.6.4.3 Sample – 4 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.34 for Sample-4, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 15 % with 5 % interval. The maximum compressive strength 12.34 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 14 days of curing and above. It was also observed that, for mix ratio 15 % cement, 10 % fly ash and 75 % IOW there is a little increase in compressive strength from 21 days of curing to 28 days of curing. However in case of other mix ratios except 10 % cement, there is a gradual change in compressive strength for 7 days to 28 days of curing. In case of 10 % cement, significant change in strength was observed from 7 days of curing to 14 days of curing. This may be due to variation in cement and fly ash ratios.

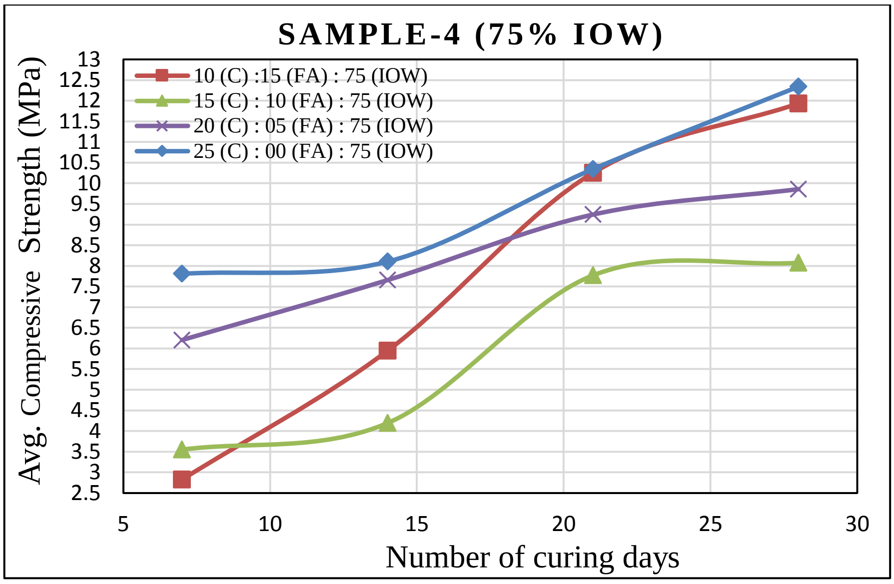

Fig. 6.34 Compressive strength vs. number of curing days

6.6.4.4 Sample – 4 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Figure 6.35 for Sample-4, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 11.92 MPa was obtained with 20 % cement and 80 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 21 days of curing and above. A significant increase in compressive strength was observed from 14 days of curing to 21 days of curing for all the mix ratios. Whereas, there is a little increase in strength when compared to 21 days and 28 days of curing for all the mix ratios.

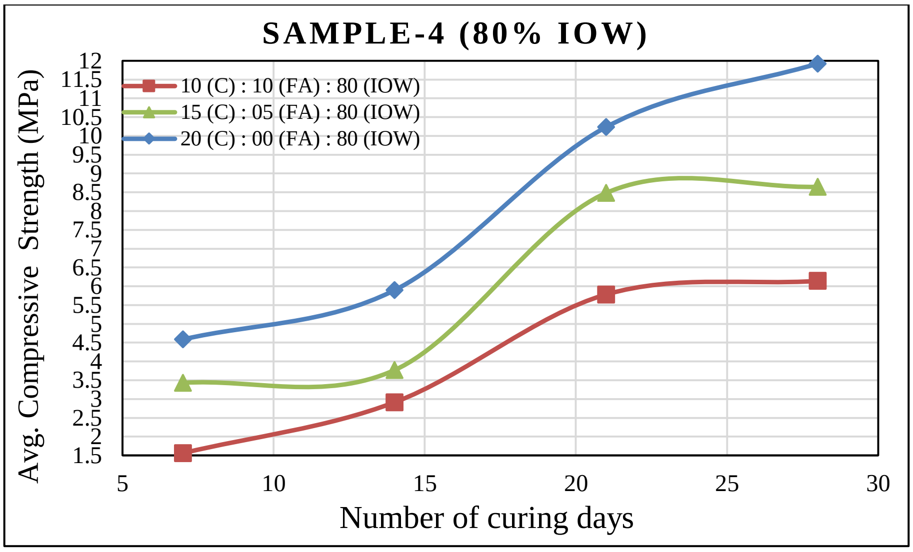

Fig. 6.35 Compressive strength vs. number of curing days

6.6.4.5 Sample – 4 with 85 % IOW

A plot of compressive strength of the bricks vs. number of curing days is shown in Figure 6.36 for Sample-4, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength 7.70 MPa was obtained with 15 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 21 days of curing period. A significant increase in compressive strength from 21 days of curing to 28 days of curing was observed with 15 % cement. Based on results it is seen that for both the mix ratios, minimum 21 days of curing is required to obtain the minimum required compressive strength as per IS Standards.

6.6.4.6 Sample – 4 with 90 % IOW

Figure 6.37 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-4 with 10 % cement, 0 % fly-ash and 90 % iron ore waste. It was observed that, there is increase in strength with respect to number of curing days. The maximum compressive strength 5.79 MPa was obtained with 10 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 21 days of curing period and above. It was also observed that with 10 % cement the compressive strength is very low, of the order of 2.30 and 2.32 for 7 days and 14 days of curing respectively. The results also reveal that with 10 % cement, minimum 21 days of curing is required to achieve minimum required compressive strength as per IS Standards.

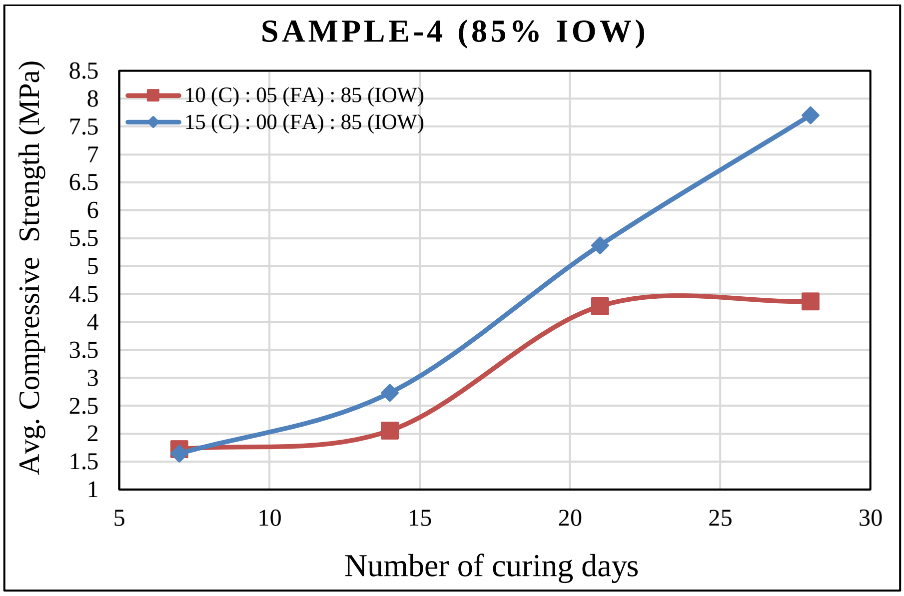

Fig. 6.36 Compressive strength vs. number of curing days

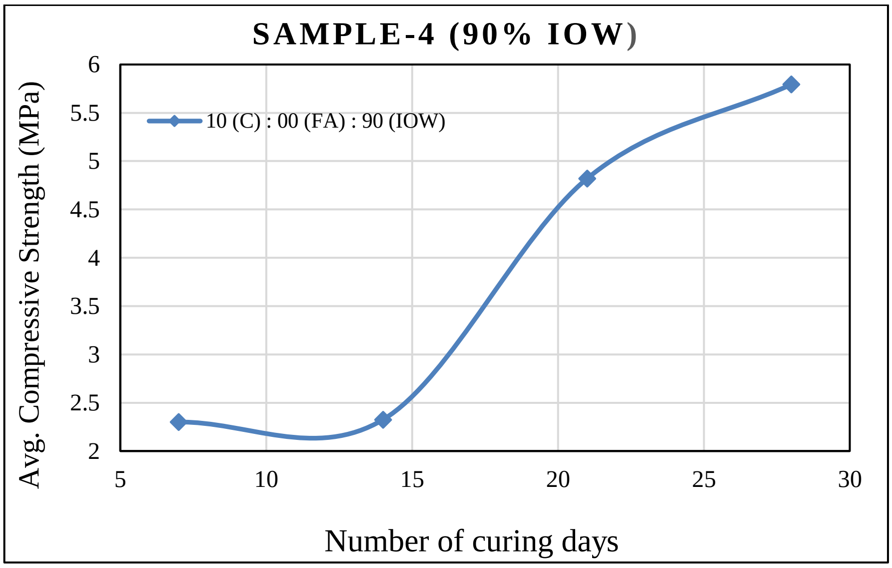

Fig. 6.37 Compressive strength vs. number of curing days

Table 6.23 Average compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 4

	Cement(C):Fly ash(FA): Iron ore waste(IOW)																			
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	5.96	6.25	8.02	17.09	4.33	7.32	7.60	10.55	4.17	5.89	6.42	10.02	3.99	5.24	5.52	8.81	2.31	2.78	3.26	5.18
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
Average compressive strength (MPa)	8.01	9.09	12.84	18.69	7.51	8.88	11.98	16.59	7.73	8.86	9.96	15.75	6.76	8.60	10.11	12.38	3.91	4.09	5.78	8.86

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Cement(C):Fly ash(FA): Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	7.81	8.10	10.34	12.34	6.20	7.66	9.24	9.86	3.55	4.19	7.77	8.07	2.82	5.94	10.25	11.93
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)							
Average compressive strength (MPa)	4.59	5.90	10.24	11.92	3.43	3.77	8.48	8.65	1.56	2.91	5.78	6.14	----			
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				----							
Average compressive strength (MPa)	1.64	2.73	5.37	7.70	1.72	2.05	4.28	4.37	----							
Proportion of material	10:00:90 (C:FA:IOW) (A)				----											
Average compressive strength (MPa)	2.3	2.324	4.82	5.794	----											

6.6.5 Jaldi Kola (JLK) / Yardammanadari (YRD) Area - (Sample – 5)

The results of average compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 5 are given in Table 6.24. The results of compressive strength for each individual bricks for all the mix ratios for sample – 5 are given in ANNEXURE-1.

Based on the results obtained from Table 6.24, the variation in compressive strength with respect to number of curing days was analysed.

6.6.5.1 Sample – 5 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.38 for Sample-5, with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 9.28 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. The minimum required compressive strength as per IS Standards of 3.5 MPa, was achieved with cement of 10 %, 25 % of fly ash and 65 % of IOW with 21 days of curing. From Fig. 6.38 it was observed that there is a gradual increase in strength with 7, 14, 21 and 28 days of curing for all the mix ratios. It was also seen that there is not much impact of number of curing days on compressive strength.

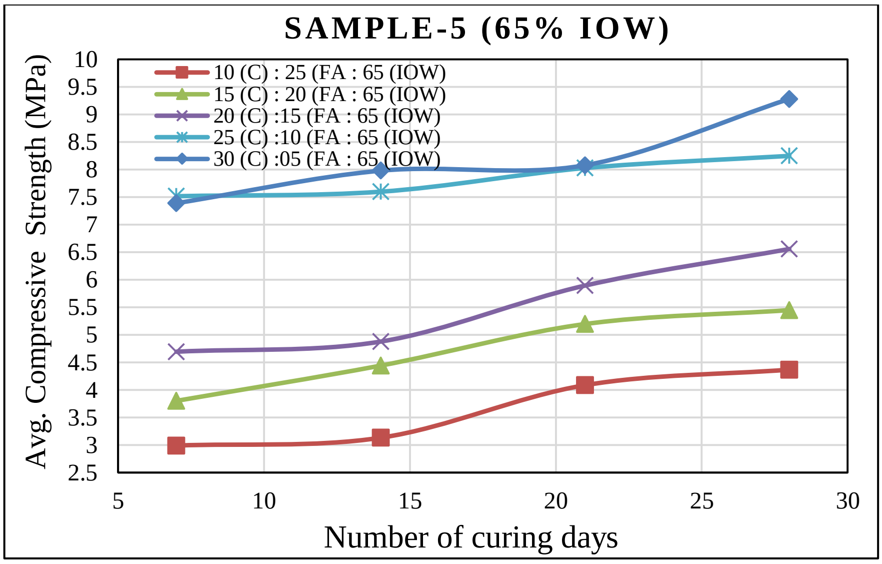

Fig. 6.38 Compressive strength vs. number of curing days

6.6.5.2 Sample – 5 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-5, with 70 % iron ore waste is shown in Fig. 6.39 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength 10.14 MPa was obtained with 30 % cement and 70 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 14 days and above. From the results obtained it was observed that, there is a gradual increase in strength with 7, 14 and 21 days of curing for all the mix ratios. A significant increase in strength was observed from 21 days of curing to 28 days of curing for all the mix ratios.

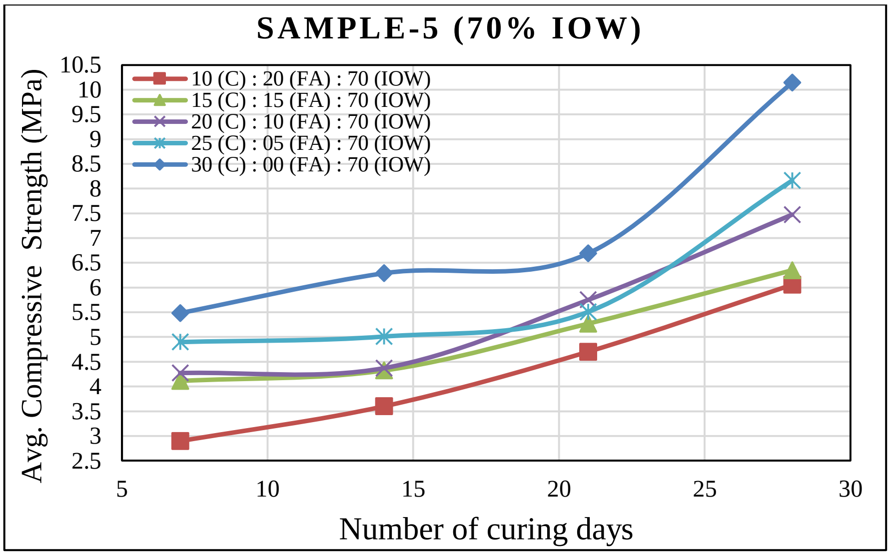

Fig. 6.39 Compressive strength vs. number of curing days

6.6.5.3 Sample – 5 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Fig. 6.40 for Sample-5, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 15 % with 5 % interval. The maximum compressive strength of 8.91 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 14 days of curing and above. It was also observed that, for mix ratio 15 % cement and 20 % cement there is slight increase in compressive strength for all the days of curing. It was also seen that there is a gradual change in strength for all the mix ratios with number of curing days. This may be due to variation in cement and fly ash ratios.

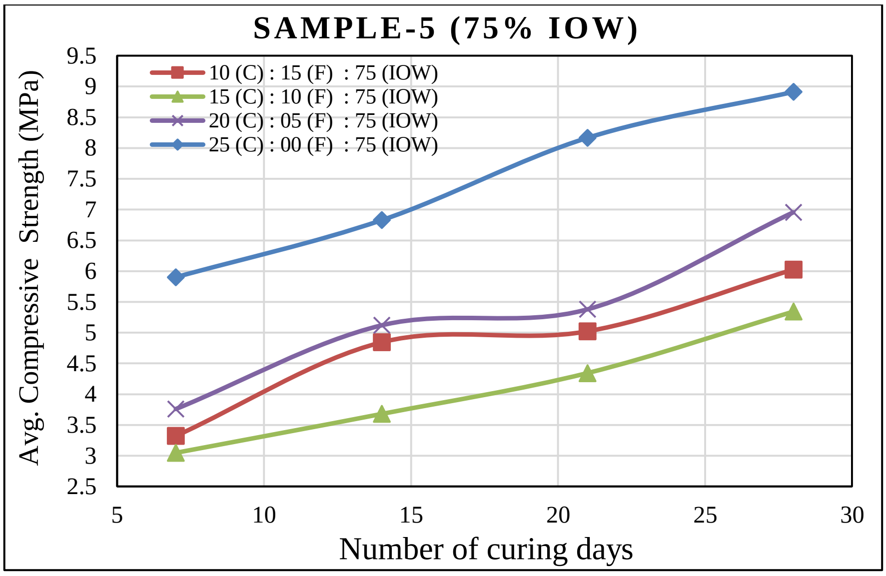

Fig. 6.40 Compressive strength vs. number of curing days

6.6.5.4 Sample – 5 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Fig. 6.41 for Sample-5, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 8.75 MPa was obtained with 20 % cement and 80 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing and above. The compressive strength observed with 10 % cement and 7 days of curing is very close to the minimum required compressive strength as per IS Standards. A significant increase in compressive strength was observed from 7 days of curing to 14 days of curing for all the mix ratios. In case of 21 days and 28 days of curing there is small increase in strength for all the mix ratios.

6.6.5.5 Sample – 5 with 85 % IOW

A plot of compressive strength of the bricks vs number of curing days is shown in Fig. 6.42 for Sample-5, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength 6.33 MPa was obtained with 15 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing period. A significant increase in compressive strength from 21 days of curing to 28 days of curing was observed with 10 % cement. In case of 15 % cement, a gradual increase in strength was observed with respect to number of curing days.

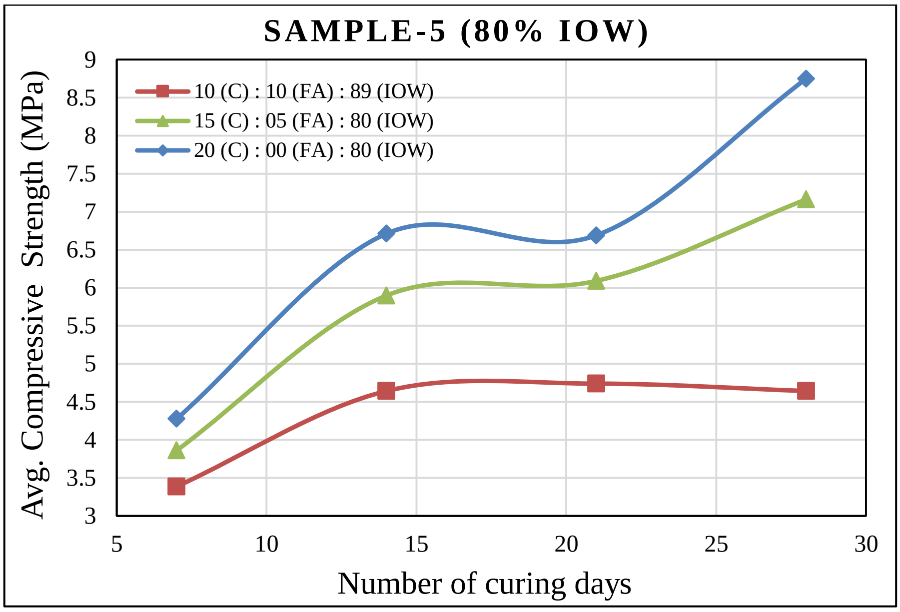

Fig. 6.41 Compressive strength vs. number of curing days

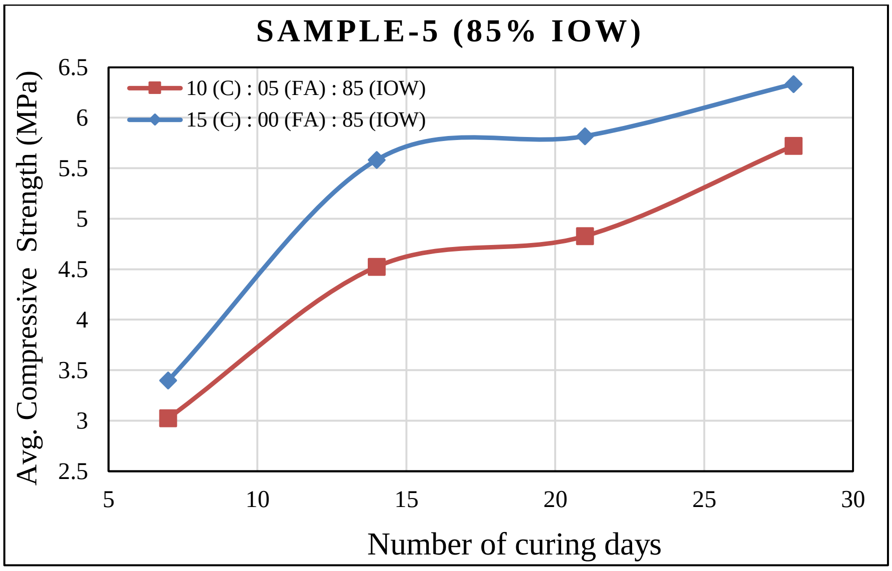

Fig. 6.42 Compressive strength vs. number of curing days

6.6.5.6 Sample – 5 with 90 % IOW

Fig. 6.43 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-5 with 10 % cement, 0 % fly-ash and 90 % iron ore waste. The maximum compressive strength 4.30 MPa was obtained with 10 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing and above. It was also observed that there is a gradual increase in strength with respect to number of curing days. The results also reveal that with 10 % cement, minimum 14 days of curing is required to achieve minimum required compressive strength as per IS Standards.

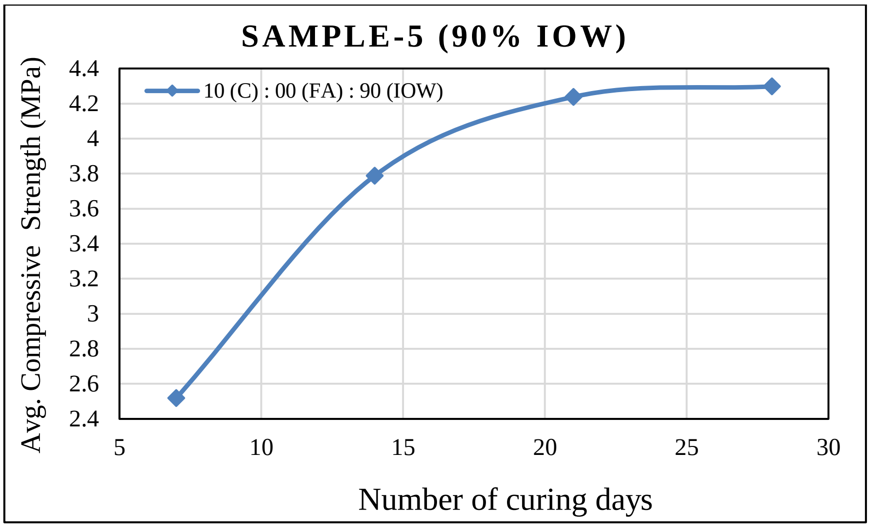

Fig. 6.43 Compressive strength vs. number of curing days

Table 6.24 Average compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 5

Cement(C):Fly ash(FA): Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	7.39	7.98	8.08	9.28	6.91	7.60	8.03	8.25	4.69	4.88	5.89	6.56	3.80	4.44	5.19	5.45	2.99	3.13	4.08	4.37
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
Average compressive strength (MPa)	5.48	6.29	6.69	10.14	4.90	5.01	5.51	8.16	4.27	4.37	5.75	7.47	4.11	4.32	5.27	6.35	2.90	3.60	4.70	6.06

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Cement(C):Fly ash(FA): Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	5.90	6.83	8.17	8.912	3.76	5.12	5.38	6.96	3.32	4.84	5.02	6.03	3.05	3.68	4.34	5.34
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)							
Average compressive strength (MPa)	4.28	6.71	6.96	8.75	3.86	5.90	6.09	7.16	3.39	4.64	4.74	5.64	----			
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				----							
Average compressive strength (MPa)	3.40	5.58	5.82	6.33	3.02	4.52	4.83	5.72	----							
Proportion of material	10:00:90 (C:FA:IOW) (A)				----											
Average compressive strength (MPa)	2.52	3.79	4.24	4.30	----											

6.6.6 Rama Kola (RMK) Area - (Sample – 9)

The results of average compressive strength of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 9 are given in Table 6.25. The results of compressive strength for each individual bricks for all the mix ratios for Sample – 9 are given in ANNEXURE-1.

Based on the results obtained from Table 6.25, the variation in compressive strength with respect to number of curing days was analysed.

6.6.6.1 Sample – 9 with 65 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.44 for Sample-9, with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. The maximum compressive strength of 17.69 MPa was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 28 days curing. The minimum required compressive strength as per IS standards of 3.5 MPa, was achieved with cement of 10 %, 25 % of fly ash and 65 % of IOW with 7 days of curing. A significant increase in strength was observed from 7 days of curing to 14 days of curing for all the mix ratios except mix ratio with 10 % cement. In case of mix ratio with 10 % cement a gradual increase in strength was observed with number of curing days. A slight increase in compressive strength with number of curing days was observed with mix ratio 10 % cement. It was also observed that with mix ratio 30 % cement and 25 % cement the compressive strength is of the order of 14.87 MPa and 14.78 MPa for 14 days of curing.

6.6.6.2 Sample – 9 with 70 % IOW

The compressive strength of bricks vs. number of curing days for Sample-9, with 70 % iron ore waste is shown in Figure 6.45 with cement being varied from 30 % to 10 % and fly-ash from 0 % to 20 % with 5 % interval. The maximum compressive strength 15.40 MPa was obtained with 30 % cement and 70 % IOW for 28 days of curing. The minimum required compressive strength as per IS Standards of 3.5 MPa was achieved with 10 % cement and with curing period of 7 days and above. From the results obtained it was observed that, there is a gradual increase in strength with 14, 21 and 28 days of curing for all the mix ratios. A significant increase in strength was observed from 7 days of curing to 14 days of curing with mix ratios 30 % cement and 25 % cement. Whereas, a gradual increase in strength is seen with mix ratio 20 % cement, 15 % cement and 10 % cement.

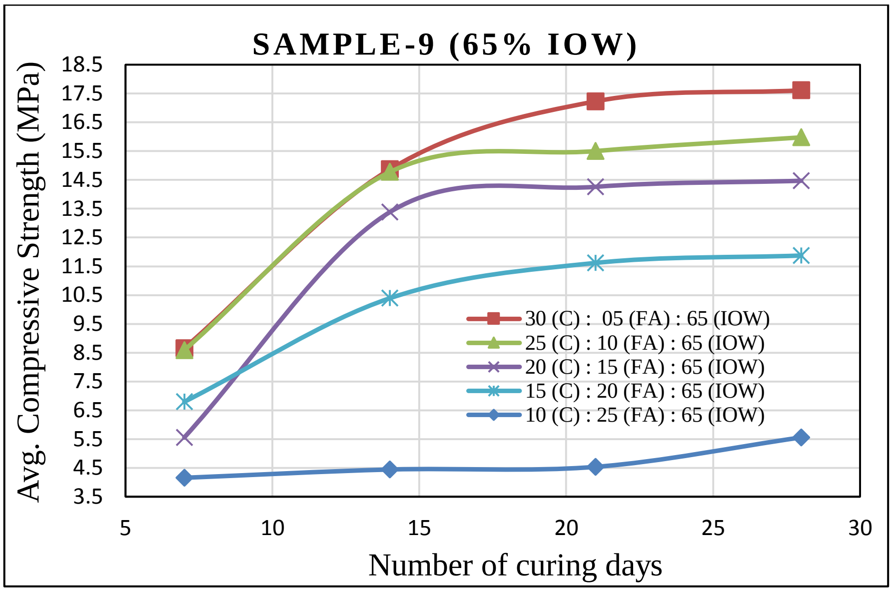

Fig. 6.44 Compressive strength vs. number of curing days

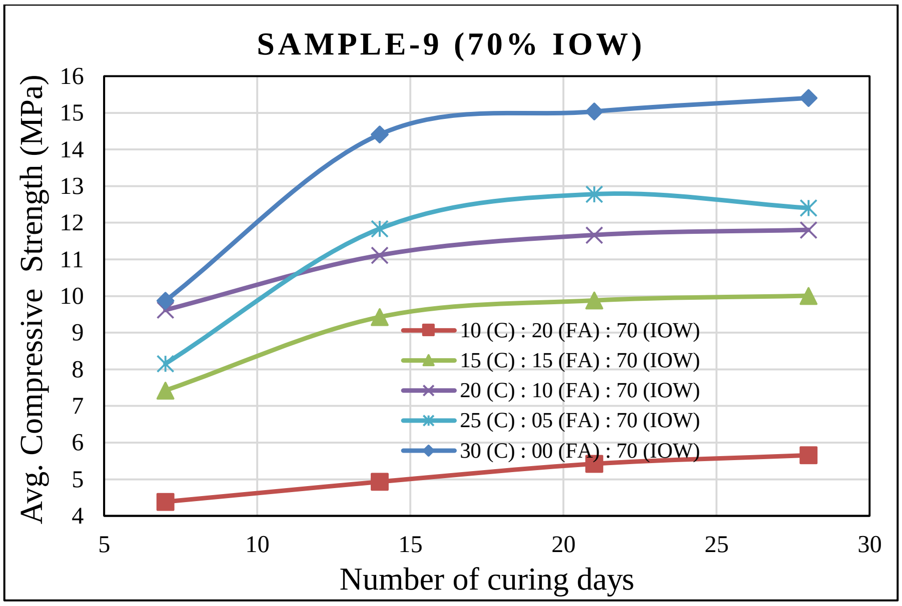

Fig. 6.45 Compressive strength vs. number of curing days

6.6.6.3 Sample – 9 with 75 % IOW

The compressive strength of the bricks vs. number of curing days is shown in Figure 6.46 for Sample-9, with 75 % iron ore waste with cement varying from 25 % to 10 % and fly-ash from 0 % to 1 5 % with 5 % interval. The maximum compressive strength 14.34 MPa was obtained with 25 % cement and 75 % IOW with 28 days of curing. The minimum required compressive strength as per IS Standards was achieved with cement content of 10 % with 7 days of curing and above. It was also observed that, there is a gradual increase in strength with respect to number of curing days for all the mix ratios. The results of compressive strength also reveal that, there is not much significant impact with number of curing days on strength.

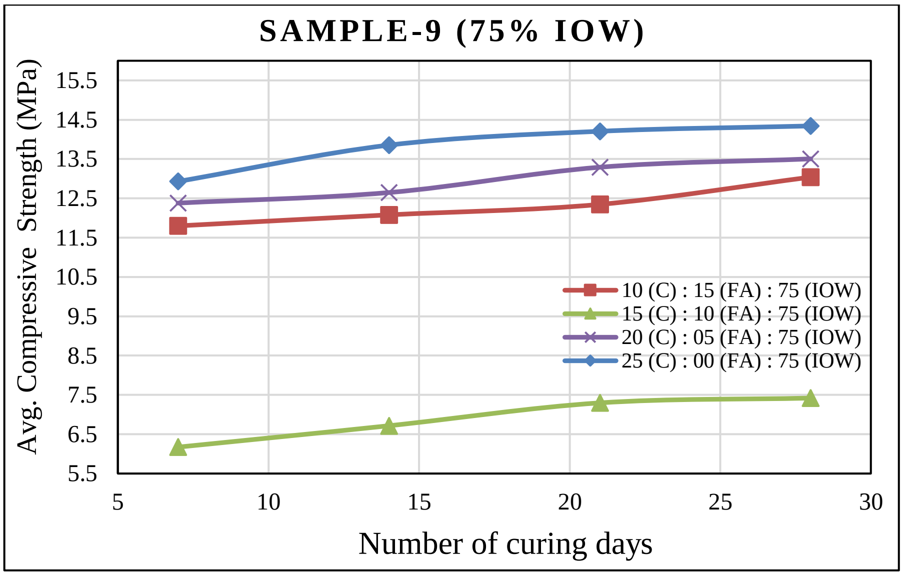

Fig. 6.46 Compressive strength vs. number of curing days

6.6.6.4 Sample – 9 with 80 % IOW

The compressive strength of bricks vs. number of curing days is shown in Figure 6.47 for Sample-9, with 80 % iron ore waste and cement varying from 20 % to 10 % and fly-ash from 0 % to 10 % with 5 % interval. The maximum compressive strength 11.34 MPa was obtained with 20 % of cement and 80 % of IOW for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 14 days of curing and above. A gradual increase in compressive strength was observed from 7 days of curing to 28 days of curing for all the mix ratios. It was also observed that with mix ratio 30 % cement and 25 % cement, the compressive strength is of the order 10.91 MPa and 10.05 MPa for 28 days of curing.

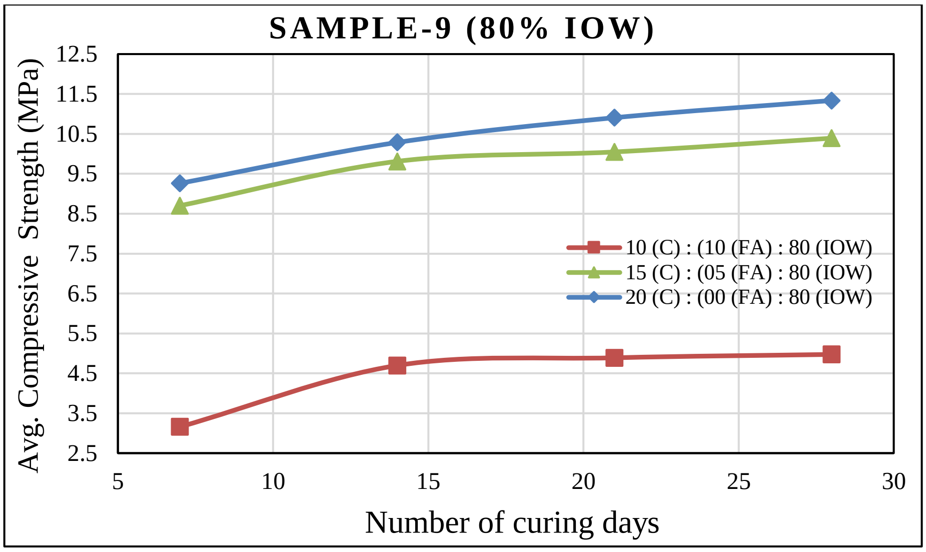

Fig. 6.47 Compressive strength vs. number of curing days

6.6.6.5 Sample – 9 with 85 % IOW

A plot of compressive strength of the bricks vs. number of curing days is shown in Figure 6.48 for Sample-9, with 85 % iron ore waste and cement varying from 15 % to 10 % and fly-ash from 0 % to 5 % with 5 % interval. The maximum compressive strength of 7.88 MPa was obtained with 15 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 7 days of curing period. A gradual increase in compressive strength with number of curing days was observed with all the mix ratios. A significant increase in strength from 7 days of curing to 14 days of curing was observed with mix ratio 10 % cement. In case of 10 % cement with 14 days of curing and 21 days of curing the increase in compressive strength is only 0.13 MPa.

6.6.6.6 Sample – 9 with 90 % IOW

Figure 6.49 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-9 with 10 % cement, 0 % fly-ash and 90 % iron ore waste. It was observed that, there is increase in strength with respect to number of curing days. The maximum compressive strength 5.71 MPa was obtained with 10 % cement for 28 days of curing. The minimum required compressive strength as per IS Standards was achieved for cement content of 10 % with 28 days of curing period and above. A significant increase in strength is seen from 21 days of curing to 28 days of curing with 10 % cement. The results also reveal that with 10 % cement, minimum 28 days of curing is required to achieve minimum required compressive strength as per IS Standards.

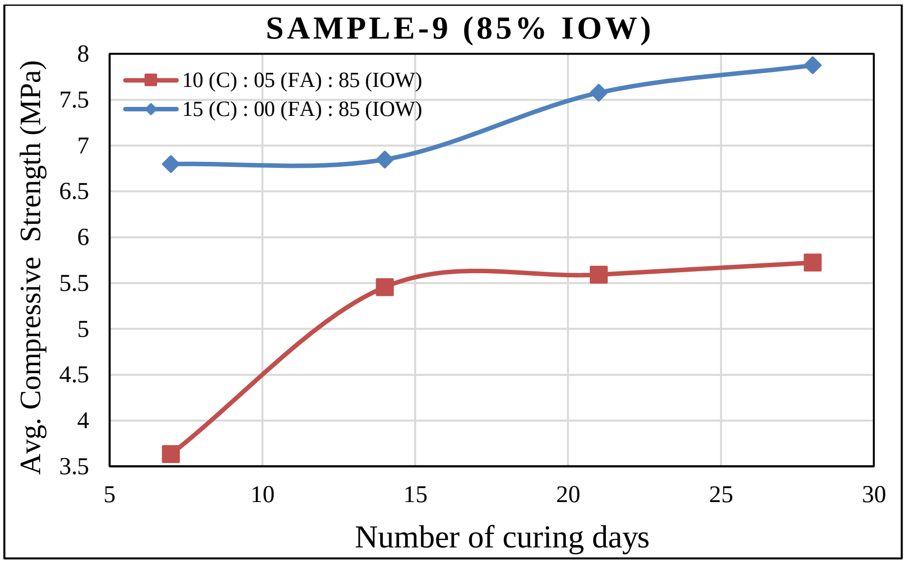

Fig. 6.48 Compressive strength vs. number of curing days

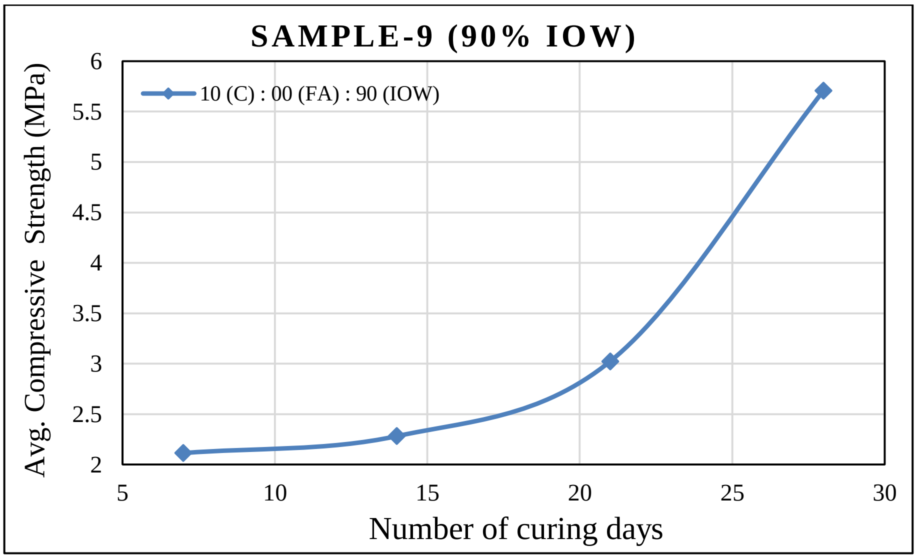

Fig. 6.49 Compressive strength vs. number of curing days

Table 6.25 Average compressive strength of bricks prepared by iron ore waste, cement and fly ash for Sample – 9

Cement(C):Fly ash(FA): Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	8.66	14.87	17.23	17.61	8.59	14.78	15.50	15.98	5.56	13.38	14.26	14.47	6.80	10.39	11.62	11.87	4.16	4.45	4.54	5.56
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
Average compressive strength (MPa)	9.87	14.41	15.04	15.40	8.16	11.84	12.78	12.40	9.62	11.11	11.67	11.81	7.42	9.43	9.88	10.01	4.38	4,93	5.42	5.65

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Cement(C):Fly ash(FA): Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average compressive strength (MPa)	12.93	13.854	14.206	14.342	12.38	12.648	13.292	13.504	11.8	12.08	12.346	13.04	6.172	6.716	7.298	7.42
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)				----			
Average compressive strength (MPa)	9.26	10.29	10.91	11.34	8.70	9.81	10.05	10.39	3.16	4.70	4.89	4.97	----			
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				----							
Average compressive strength (MPa)	6.80	6.85	7.58	7.88	3.63	5.46	5.59	5.72	----							
Proportion of material	10:00:90 (C:FA:IOW) (A)				----											
Average compressive strength (MPa)	2.11	2.28	3.02	5.71	----											

6.7 Results of Water Absorption

6.7.1 Seelu Kola Area (Sample – 1)

The results of percentage of water absorption obtained from bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for Sample – 1 are given in Table 6.26 to Table 6.31.

The percentage of water absorption of the bricks vs. number of curing days is shown in Figure 6.50 for Sample-1, which indicates the variation in water absorption percentage with respect to number of curing days. The bricks were prepared with 65 % iron ore waste as constant with cement content varied from 30 % to 5 % and fly-ash from 5 % to 25 % with an interval of 5 %. In total, for each mix ratio, there were 20 bricks prepared and tested for its water absorption. Out of these 20 bricks, for each curing period i.e. 7, 14, 21 and 28 days, 5 bricks were tested and results obtained were tabulated in Table 6.26 to 6.31. The maximum percentage of water absorption of 14.53 was obtained with 30 % cement, 5 % fly ash and 65 % IOW with 7 days of curing. It is clear from the Fig. 6.50 that the results obtained from all the bricks of Sample - 1 are within the limit for water absorption as per IS Standards (< 20 % when immersed in water for 24 hr.) for all the mix ratios with different curing periods of 7, 14, 21 and 28 days. The minimum percentage of water absorption of 5.48 was achieved with mix ratio 5 % cement and 28 days of curing. Further, for all the mix ratios, a significant decrease in percentage of water absorption was observed from 7 days of curing to 14 days of curing. In case of 14, 21 and 28 days of curing, a gradual decrease was observed. It was also seen that, as we decrease the cement percentage, the water absorption also decreases gradually.

Similar trend was shown by Sample – 1 with 70 %, 75 %, 80 %, 85 % and 90 % IOW which is shown clearly from Figure 6.51 to Figure 6.55, respectively.

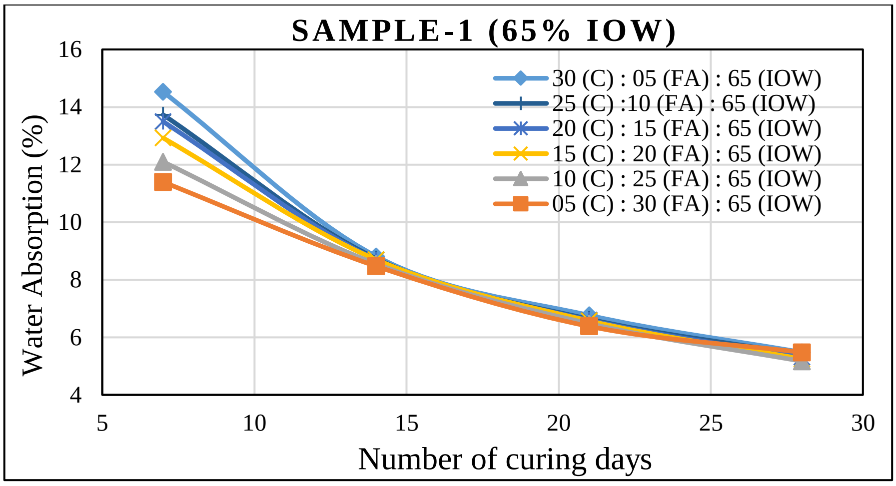


Fig. 6.50 Water absorption vs. number of curing days

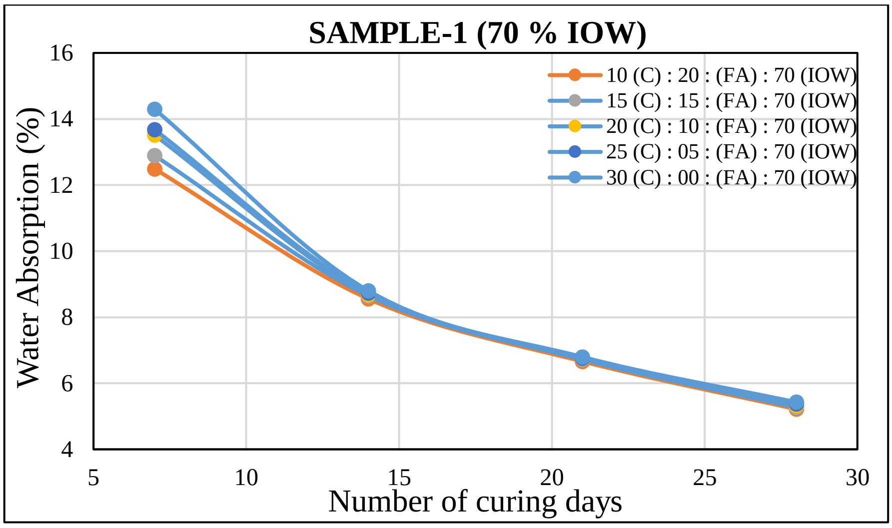


Fig. 6.51 Water absorption vs. number of curing days

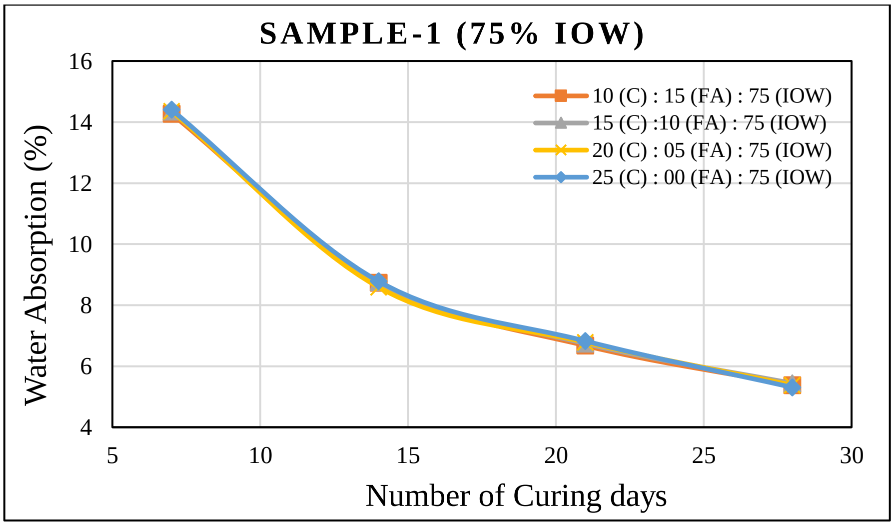


Fig. 6.52 Water absorption vs. number of curing days

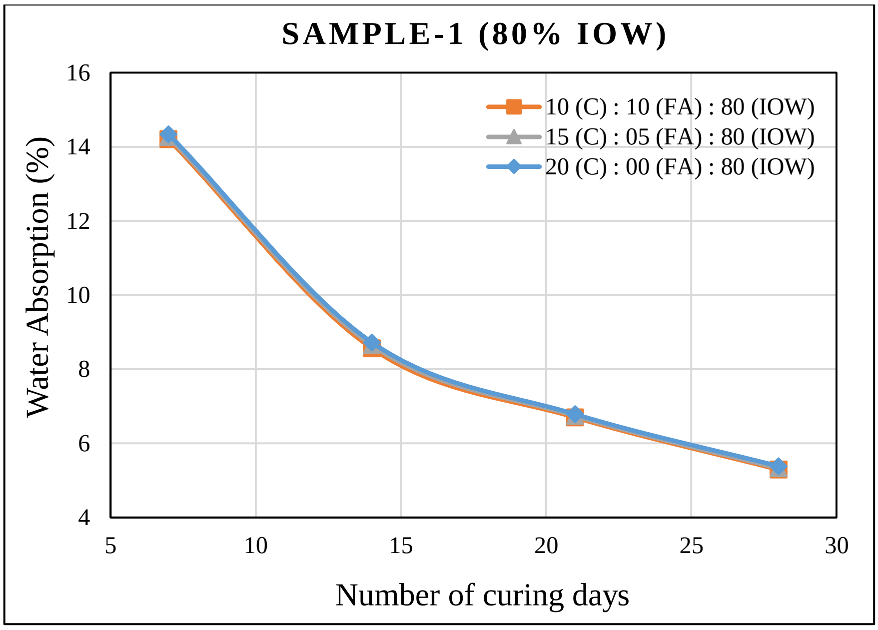


Fig. 6.53 Water absorption vs. number of curing days

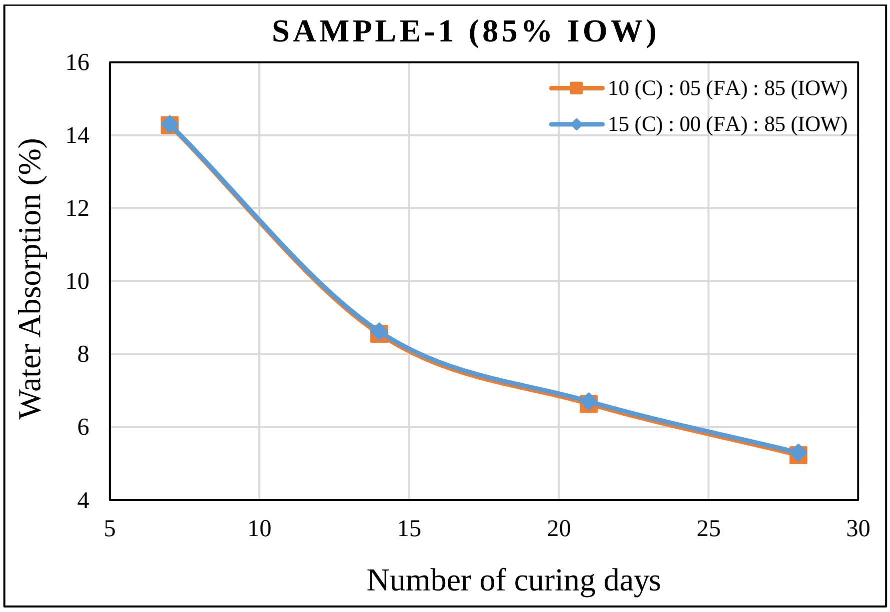


Fig. 6.54 Water absorption vs. number of curing days

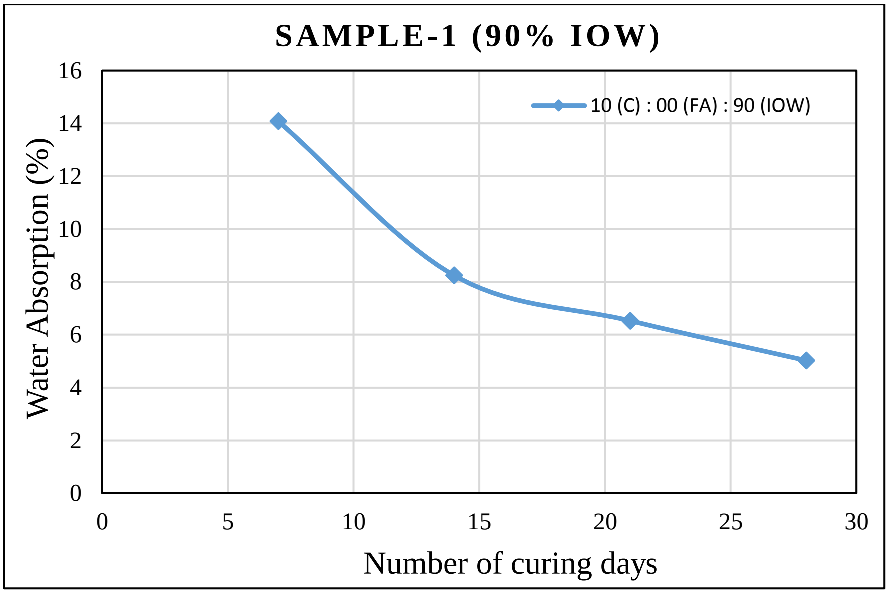


Fig. 6.55 Water absorption vs. number of curing days

A similar trend in results were observed with other sample locations i.e. with Sample-2, Sample-3, Sample-4, Sample-5 and Sample-9. The detailed percentage of water absorption obtained for all the mix ratios for these locations were well within the maximum water absorption percentage limit which are given in ANNEXURE-III and ANNEXURE-IV.

Table 6.26 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 65 % IOW

Cement (C):Fly ash (FA): Iron ore waste (IOW)																
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	14.44	8.80	6.60	5.45	13.80	8.75	6.64	5.42	13.50	8.70	6.62	5.38	12.98	8.65	6.60	5.28
S2	14.60	8.85	6.80	5.50	13.75	8.77	6.60	5.40	13.45	8.72	6.60	5.36	12.80	8.62	6.57	5.24
S3	14.50	8.75	6.85	5.48	13.70	8.74	6.62	5.38	13.55	8.69	6.59	5.25	12.95	8.64	6.55	5.26
S4	14.65	8.84	6.82	5.46	13.76	8.70	6.64	5.44	13.50	8.71	6.60	5.28	13.00	8.55	6.58	5.20
S5	14.45	8.83	6.75	5.49	13.65	8.72	6.66	5.37	13.48	8.67	6.58	5.30	12.90	8.58	6.56	5.25
Average Water Absorption (%))	14.53	8.81	6.76	5.48	13.73	8.74	6.63	5.40	13.50	8.70	6.60	5.31	12.93	8.70	6.57	5.25

Contd………

Cement (C):Fly ash (FA): Iron ore waste (IOW)								
Proportion of material	10:25:65 (C:FA:IOW) (E)				05:30:65 (C:FA:IOW) (F)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	12.90	8.60	6.48	5.20	11.20	8.45	6.40	5.45
S2	11.98	8.58	6.44	5.18	11.50	8.48	6.42	5.50
S3	11.95	8.56	6.45	5.15	11.45	8.46	6.38	5.48
S4	11.85	8.52	6.50	5.17	11.48	8.50	6.36	5.46
S5	11.80	8.50	6.52	5.14	11.35	8.47	6.35	5.49
Average Water Absorption (%)	12.10	8.55	6.48	5.17	11.40	8.47	6.38	5.48

Table 6.27 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 70 % IOW

Cement (C):Fly ash (FA): Iron ore waste (IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	14.45	8.78	6.85	5.43	13.70	8.75	6.82	5.36	13.54	8.72	6.78	5.35	12.96	8.71	6.69	5.30	12.84	8.60	6.70	5.23
S2	14.25	8.81	6.81	5.40	13.65	8.70	6.77	5.39	13.52	8.69	6.76	5.32	12.86	8.66	6.73	5.27	12.80	8.56	6.68	5.20
S3	14.20	8.83	6.78	5.44	13.68	8.76	6.74	5.41	13.50	8.67	6.74	5.29	12.89	8.62	6.71	5.29	12.83	8.59	6.66	5.19
S4	14.22	8.77	6.75	5.46	13.66	8.74	6.71	5.37	13.48	8.65	6.71	5.30	12.85	8.6	6.75	5.25	11.98	8.52	6.65	5.21
S5	14.36	8.80	6.79	5.40	13.69	8.71	6.73	5.35	13.51	8.70	6.73	5.34	12.90	8.63	6.70	5.22	12.00	8.50	6.62	5.25
Average Water Absorption (%)	14.30	8.80	6.80	5.43	13.68	8.73	6.75	5.38	13.51	8.69	6.74	5.32	12.89	8.64	6.72	5.27	12.49	8.55	6.66	5.22

Table 6.28 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 75 % IOW

Cement (C): Fly ash (FA): Iron ore waste (IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
B1	14.39	8.70	6.80	5.31	14.37	8.79	6.80	5.40	14.38	8.77	6.80	5.41	14.31	8.75	6.71	5.40
B2	14.37	8.82	6.83	5.29	14.35	8.76	6.77	5.36	14.36	8.80	6.72	5.49	14.27	8.71	6.70	5.40
B3	14.43	8.76	6.85	5.34	14.39	8.82	6.84	5.43	14.34	8.75	6.75	5.45	14.29	8.74	6.68	5.34
B4	14.40	8.8	6.81	5.32	14.36	8.80	6.76	5.39	14.31	8.74	6.71	5.44	14.25	8.76	6.65	5.36
B5	14.44	8.83	6.84	5.27	14.32	7.78	6.75	5.32	14.33	8.72	6.73	5.42	14.23	8.73	6.63	5.39
Average Water Absorption (%))	14.41	8.78	6.83	5.31	14.36	8.59	6.78	5.38	14.34	8.76	6.74	5.44	14.27	8.74	6.67	5.38

Table 6.29 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 80 % IOW

Cement (C):Fly ash (FA): Iron ore waste (IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	14.35	8.68	6.79	5.39	14.26	8.65	6.71	5.31	14.20	8.57	6.67	5.30
S2	14.38	8.77	6.82	5.41	14.29	8.63	6.77	5.32	14.24	8.53	6.63	5.28
S3	14.30	8.73	6.77	5.37	14.30	8.69	6.76	5.36	14.22	8.60	6.70	5.33
S4	14.36	8.69	6.75	5.35	14.27	8.67	6.73	5.34	14.19	8.59	6.61	5.29
S5	14.31	8.75	6.80	5.40	14.23	8.61	6.75	5.30	14.17	8.54	6.89	5.26
Average Water Absorption (%)	14.34	8.72	6.79	5.38	14.27	8.65	6.74	5.33	14.20	8.57	6.70	5.29

Table 6.30 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 85 % IOW

Cement (C):Fly ash (FA): Iron ore waste (IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	14.34	8.61	6.73	5.31	14.29	8.57	6.65	5.24
S2	14.30	8.65	6.70	5.29	14.25	8.51	6.63	5.22
S3	14.32	8.67	6.74	5.35	14.33	8.60	6.67	5.26
S4	14.27	8.59	6.67	5.30	14.28	8.57	6.61	5.25
S5	14.29	8.60	6.69	5.27	14.26	8.55	6.64	5.21
Average Water Absorption (%)	14.30	8.62	6.71	5.30	14.28	8.56	6.64	5.24

Table 6.31 Water absorption percentage of bricks prepared using iron ore waste, cement and fly ash for Sample – 1 with 90 % IOW

Cement (C):Fly ash (FA): Iron ore waste (IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	14.10	8.26	6.55	5.09
S2	14.13	8.22	6.51	5.06
S3	14.07	8.20	6.57	5.02
S4	14.09	8.25	6.49	4.97
S5	14.05	8.29	6.53	4.99
Average Water Absorption (%)	14.09	8.24	6.53	5.03

6.8 RESULTS OF COMPRESSIVE STRENGTH OF BRICKS WITH LESS THAN 10% CEMENT

Based on the results obtained so far, it is clear that bricks with cement content of 10 % and above meet the desired BIS standards of compressive strength and water absorption. Further bricks with cement content of 5 % and less neither meet the BIS standards nor are stable once removed from the mould. Hence it was decided to reduce the cement content in the bricks from 9 % to 6 % to get exactly at which cement percentage, the brick remains stable meeting BIS standards. However, the results have been reported with increasing cement percentage up to 9 %.

6.8.1 Compressive Strength (Sample – 1, SK)

6.8.1.1 Bricks prepared with 65 % IOW, 7 % Cement and 28 % Fly ash (Sample – 1, SK)

The compressive strength results obtained for different curing periods for bricks prepared with mix ratio of 7 % cement (65 % IOW, 7 % Cement and 28 % Fly ash) are given in Table 6.32.

Figure 6.56 shows the bricks prepared with 65 % IOW, 7 % cement and 28 % fly ash. Since the cement content was only 7 %, the bricks prepared were with broken edges. This may be due to lower binding property of the mixture because of lesser cement percentage. Since with 7 % cement content, the bricks prepared were not stable and were with broken edges, it was decided not to make any attempt in preparing bricks containing 6 % cement. It was observed that the compressive strength results obtained with 7 % cement content were very low and not meeting the BIS standards.

Fig. 6.56 Bricks with 65% IOW, 7% Cement and 28% Fly ash

6.8.1.2 Bricks prepared with 65 % IOW, 8 % Cement and 27 % Fly ash

Figure 6.57 shows the prepared bricks with 65 % IOW, 8 % cement and 27 % fly ash. Since the cement content was only 8 %, the bricks prepared were with broken edges, similar to the bricks prepared with 7 % cement content. The results of compressive strength obtained for different curing period are given in Table 6.32. . It was observed that the compressive strength results obtained with 8 % cement content were very low and does not meet the required BIS norms as in case of brick with 7 % cement.

Fig. 6.57 Bricks with 65% IOW, 8% Cement and 27% Fly ash

6.8.1.3 Bricks prepared with 65 % IOW, 9 % Cement and 26 % Fly ash

Figure 6.58 shows the prepared bricks with 65 % IOW, 9 % cement and 26 % fly ash. The bricks prepared with 9 % cement were in regular shape and the result of compressive strength for different curing period are given in Table 6.32.

Fig. 6.58 Bricks with 65% IOW, 9% cement and 26% fly ash

Figure 6.59 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-1 with 7 %, 8 % and 9 % cement and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 %. From the results obtained (Table 6.32), it was observed that with cement content of 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing. It was also observed that with 9 % cement content, the minimum required strength was obtained with 28 days of curing.

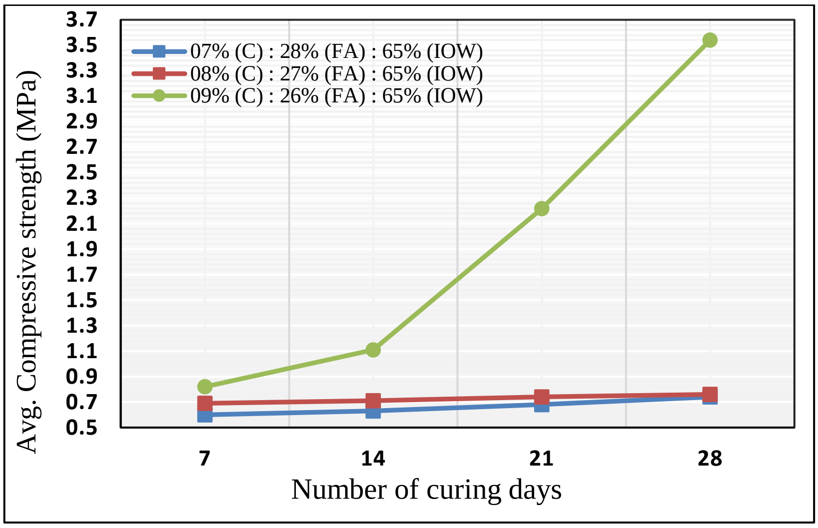


Fig. 6.59 Compressive strength vs. number of curing days (Sample – 1, SK)

Table 6.32 Compressive strength of bricks prepared with cement content of 7%, 8% and 9% (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.59	0.64	0.62	0.71	0.68	0.70	0.71	0.74	0.82	1.20	1.90	3.60
S2	0.61	0.62	0.69	0.76	0.66	0.73	0.76	0.77	0.85	1.00	2.20	3.55
S3	0.57	0.65	0.67	0.74	0.70	0.69	0.75	0.79	0.83	0.98	2.35	3.45
S4	0.62	0.60	0.71	0.77	0.69	0.75	0.73	0.75	0.79	1.25	2.40	3.52
S5	0.60	0.63	0.70	0.70	0.71	0.70	0.77	0.74	0.80	1.10	2.25	3.58
Average compressive strength (MPa)	**0.60**	**0.63**	**0.68**	**0.74**	**0.69**	**0.71**	**0.74**	**0.76**	**0.818**	**1.106**	**2.22**	**3.54**

6.8.2 Water Absorption (Sample – 1, SK)

Figure 6.60 shows a plot of percentage of water absorption of the bricks vs. number of curing days for Sample-1with 7 %, 8 % and 9 % cement and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % which was drawn using the data of Table 6.33.

From Table 6.33, it was observed that bricks prepared with cement content of 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per BIS Standards (< 20% when immersed in water for 24 hrs.) for all the days of curing period.

Table 6.33 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	11.50	8.52	7.50	6.40	11.60	8.67	7.58	6.75	11.70	8.96	7.65	6.18
S2	11.52	8.45	7.45	6.45	11.62	8.70	7.55	6.80	11.78	9.00	7.69	6.15
S3	11.54	8.49	7.55	6.39	11.59	8.69	7.60	6.79	11.75	8.90	7.70	6.22
S4	11.57	8.42	7.52	6.52	11.64	8.65	7.62	6.77	11.69	8.97	7.77	6.19
S5	11.59	8.48	7.55	6.50	11.65	8.72	7.59	6.82	11.67	9.02	7.72	6.20
Average water absorption (%)	**11.53**	**8.47**	**7.51**	**6.44**	**11.61**	**8.68**	**7.59**	**6.78**	**11.73**	**8.96**	**7.70**	**6.19**

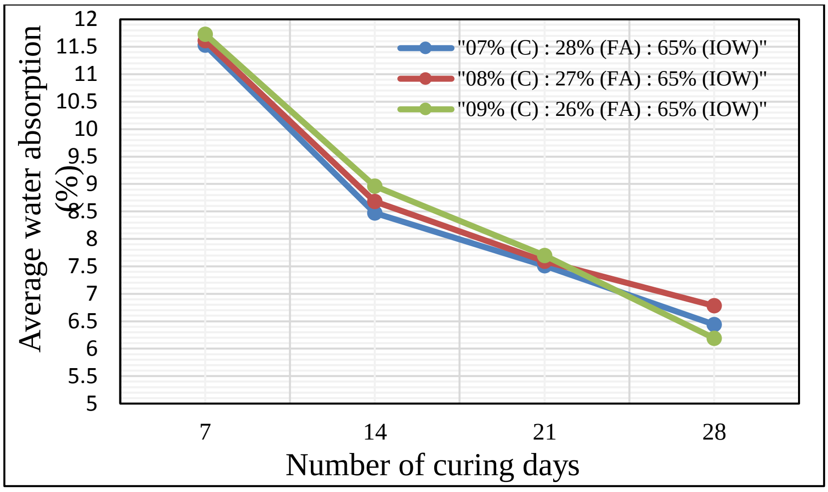


Fig. 6.60 Percentage of water absorption vs. number of curing days

6.8.3 Compressive strength and water absorption of bricks prepared with cement content 7 %, 8 % and 9 % (Sample – 2, KMK)

The results of compressive strength of bricks prepared with 7 %, 8 % and 9 % cement content, and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % is given in Table 6.34. Figure 6.61 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-2. From the results obtained (Table 6.3 4), it was observed that with cement content 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing. However, with 9 % of cement content, the minimum required strength was obtained with 14 days of curing and above.

Figure 6.62 shows a plot of percentage water absorption of bricks vs. number of curing days for Sample-2. From Table 6.35, it was observed that the bricks prepared with cement content of 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per IS Standards for all the days of curing period.

Table 6.34 Compressive strength of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.69	0.76	0.85	1.09	1.98	2.10	2.35	2.50	3.00	3.85	4.50	5.30
S2	0.70	0.82	0.90	1.10	2.05	2.15	2.40	2.65	3.20	3.60	4.55	5.25
S3	0.65	0.80	0.88	0.99	2.00	2.08	2.30	2.75	3.40	3.65	4.59	5.32
S4	0.59	0.79	0.94	1.05	1.95	2.17	2.25	2.55	3.35	3.76	4.60	5.29
S5	0.60	0.75	0.89	1.00	2.01	2.13	2.45	2.70	3.25	3.80	4.65	5.27
Average compressive strength (MPa)	**0.65**	**0.78**	**0.89**	**1.05**	**2.00**	**2.13**	**2.35**	**2.63**	**3.24**	**3.73**	**4.58**	**5.29**

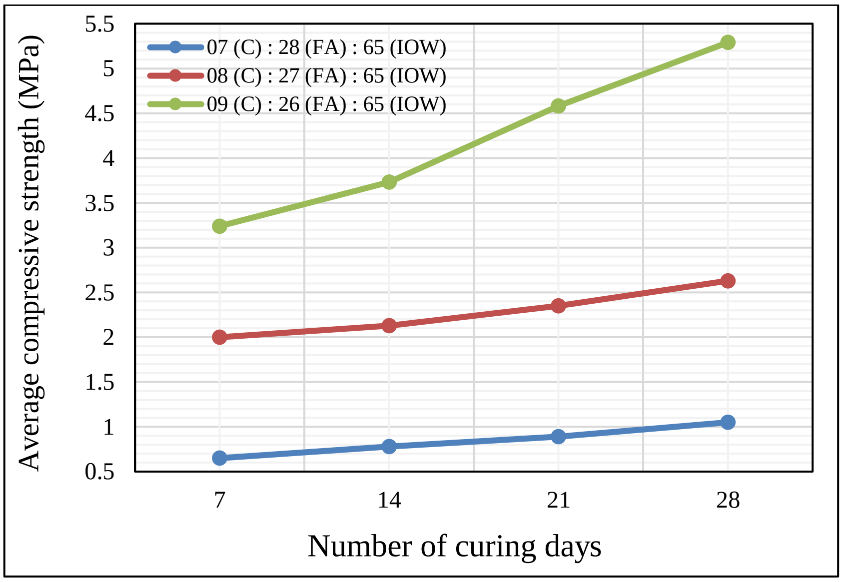


Fig. 6.61 Compressive strength vs. number of curing days

Table 6.35 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	11.35	7.02	4.05	4.20	11.55	7.20	4.19	4.35	11.99	7.45	5.00	4.50
S2	11.30	6.99	4.15	4.25	11.50	7.10	4.24	4.30	11.90	7.50	4.89	4.45
S3	11.28	7.00	4.09	4.29	11.45	7.07	4.2	4.32	11.95	7.47	4.95	4.49
S4	11.33	7.04	4.13	4.27	11.52	7.15	4.25	4.38	11.97	7.52	4.90	4.47
S5	11.37	7.06	4.17	4.30	11.49	7.18	4.28	4.35	11.93	7.49	5.10	4.43
Average water absorption (%)	**11.33**	**7.02**	**4.12**	**4.26**	**11.50**	**7.14**	**4.23**	**4.34**	**11.95**	**7.49**	**4.97**	**4.47**

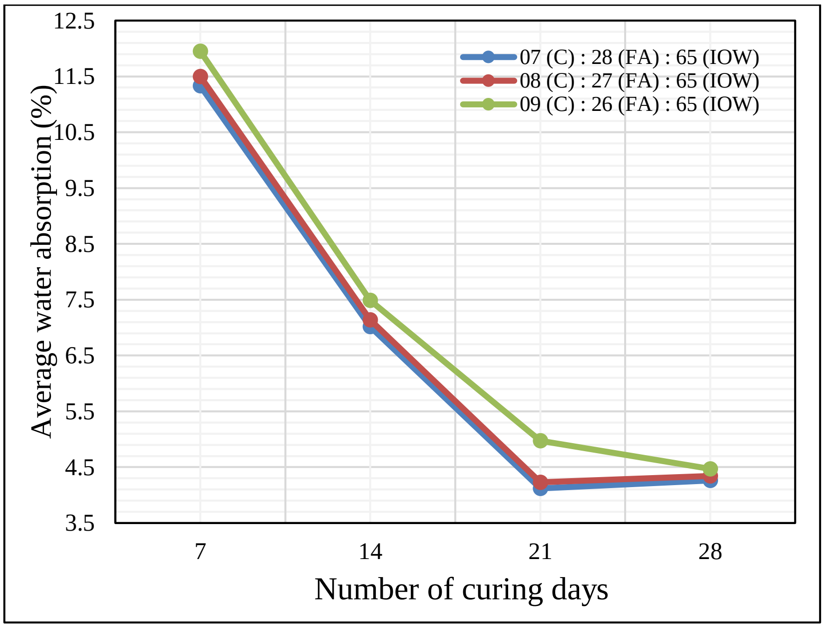


Fig. 6.62 Percentage of water absorption vs. number of curing days

6.8.4 Compressive strength and water absorption of bricks prepared with cement content 7 %, 8 % and 9% (Sample – 3, NK)

The results of compressive strength of bricks prepared with cement content of 7 %, 8 % and 9 % and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % is given in Table 6.36. Figure 6.63 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-3. From the results obtained (Table 6.36), it was observed that with cement content 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing as like Sample – 1 and Sample - 2. However, with 9 % of cement content, the minimum required strength was obtained with 14 days of curing and above.

Figure 6.64 shows a plot of water absorption percentage of the bricks vs. number of curing days for Sample-3. From Table 6.37, it was observed that bricks prepared with cement content of 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per IS Standards for all the days of curing period.

Table 6.36 Compressive strength of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.75	0.84	0.95	1.05	2.25	2.45	2.86	3.00	3.29	3.54	3.99	4.60
S2	0.71	0.89	1.00	1.01	2.19	2.36	2.78	2.98	3.22	3.56	4.02	4.65
S3	0.70	0.82	0.99	1.08	2.23	2.39	2.80	2.95	3.20	3.50	4.05	4.69
S4	0.73	0.90	0.92	1.10	2.20	2.43	2.84	2.90	3.26	3.53	3.98	4.55
S5	0.69	0.80	0.90	1.06	2.18	2.40	2.79	2.93	3.25	3.55	3.95	4.59
Average compressive strength (MPa)	**0.72**	**0.85**	**0.95**	**1.06**	**2.21**	**2.41**	**2.81**	**2.95**	**3.24**	**3.54**	**4.00**	**4.62**

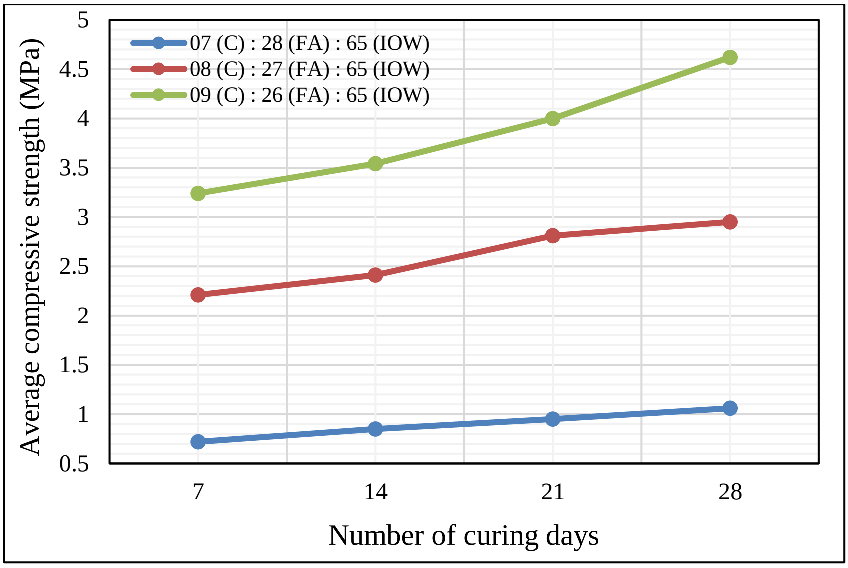


Fig. 6.63 Compressive strength vs. number of curing days

Table 6.37 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	10.09	6.90	4.11	3.98	11.00	7.10	4.29	4.09	11.12	6.99	4.09	3.82
S2	10.06	6.86	4.00	3.93	11.05	7.13	4.33	4.01	11.17	6.96	4.05	3.85
S3	10.03	6.95	4.03	3.95	11.10	7.15	4.35	4.07	11.20	6.93	4.01	3.89
S4	10.10	6.88	4.05	3.99	11.07	7.09	4.30	3.99	11.19	7.00	4.07	3.91
S5	10.05	6.93	4.07	3.90	11.03	7.17	4.37	4.05	11.15	6.95	4.10	3.90
Average water absorption (%)	**10.07**	**6.90**	**4.05**	**3.95**	**11.05**	**7.13**	**4.33**	**4.04**	**11.17**	**6.97**	**4.06**	**3.87**

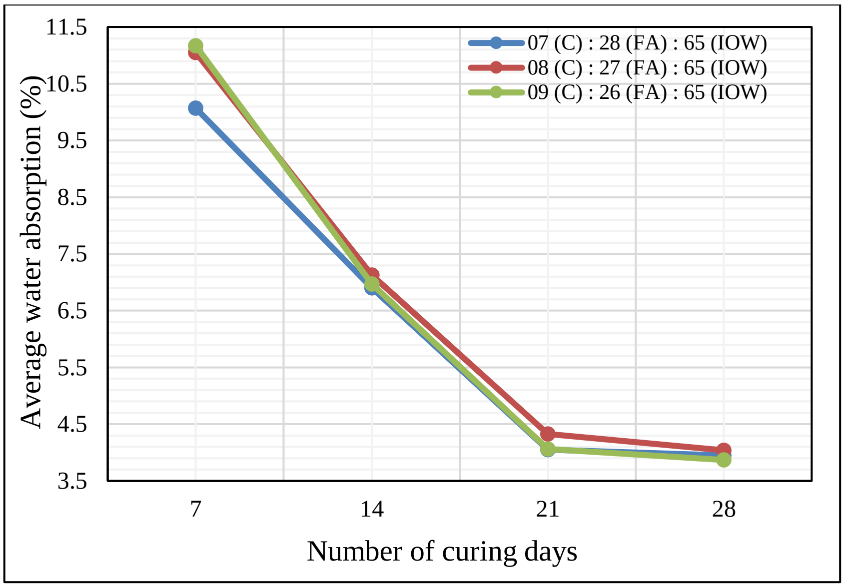


Fig. 6.64 Percentage of water absorption vs. number of curing days

6.8.5 Compressive strength and water absorption of bricks prepared with cement content 7 %, 8 % and 9 % (Sample – 4, ANKAMNAL)

Similarly, the results of compressive strength of bricks prepared with cement content of 7 %, 8 % and 9 % and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % is given in Table 6.38. Figure 6.65 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-4. From the results obtained (Table 6.38), it was observed that with cement content 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing as in the previous cases. However, with 9 % of cement content, the minimum required strength was obtained with 28 days of curing and above.

Figure 6.66 shows a plot of water absorption percentage of the bricks vs. number of curing days for Sample-4. From Table 6.39, it was observed that bricks prepared with cement ratio 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per IS Standards for all the days of curing period.

Table 6.38 Compressive strength of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-4, ANKAMNAL)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.68	0.70	0.79	0.99	1.98	2.02	2.25	2.88	2.10	2.45	3.20	3.88
S2	0.65	0.68	0.82	1.02	1.89	2.00	2.29	2.90	2.03	2.50	3.10	3.79
S3	0.55	0.75	0.80	0.92	2.00	2.05	2.20	2.95	2.08	2.40	3.13	3.85
S4	0.59	0.73	0.85	0.96	1.90	1.99	2.24	2.86	2.05	2.42	3.09	3.80
S5	0.60	0.70	0.80	0.90	1.95	1.96	2.27	2.97	2.00	2.39	3.11	3.76
Average compressive strength (MPa)	**0.61**	**0.71**	**0.81**	**0.96**	**1.94**	**2.00**	**2.25**	**2.91**	**2.05**	**2.43**	**3.13**	**3.82**

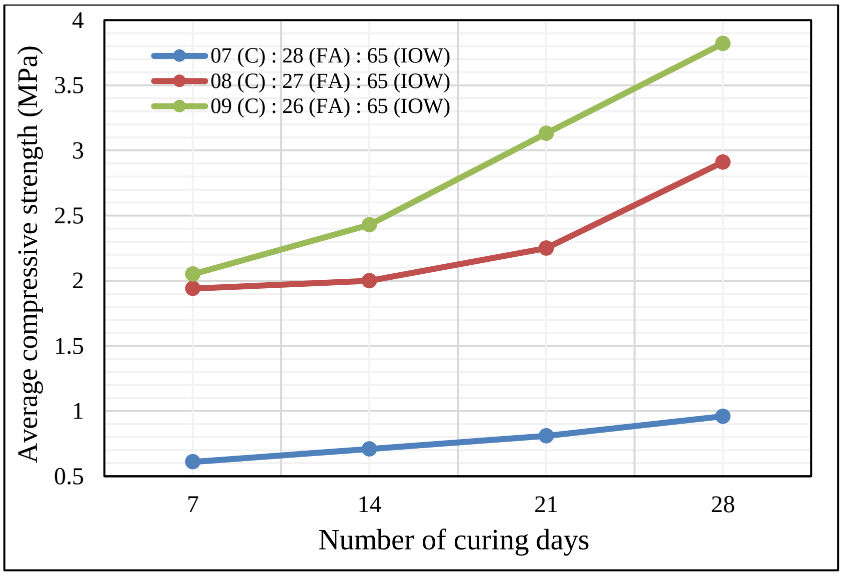


Fig. 6.65 Compressive strength vs. number of curing days

Table 6.39 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-4, ANKAMNAL)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	12.56	7.20	4.29	3.97	12.78	7.46	4.89	4.15	12.79	7.55	5.09	4.4
S2	12.49	7.15	4.25	3.89	12.80	7.43	4.90	4.10	12.69	7.56	5.01	4.35
S3	12.53	7.17	4.30	3.99	12.77	7.40	4.87	4.17	12.65	7.50	5.00	4.30
S4	12.50	7.11	4.22	3.92	12.83	7.47	4.91	4.12	12.67	7.53	4.99	4.39
S5	12.55	7.19	4.27	3.95	12.80	7.42	4.85	4.14	12.63	7.51	5.03	4.33
Average water absorption (%)	**12.53**	**7.16**	**4.27**	**3.94**	**12.80**	**7.44**	**4.88**	**4.14**	**12.69**	**7.53**	**5.02**	**4.35**

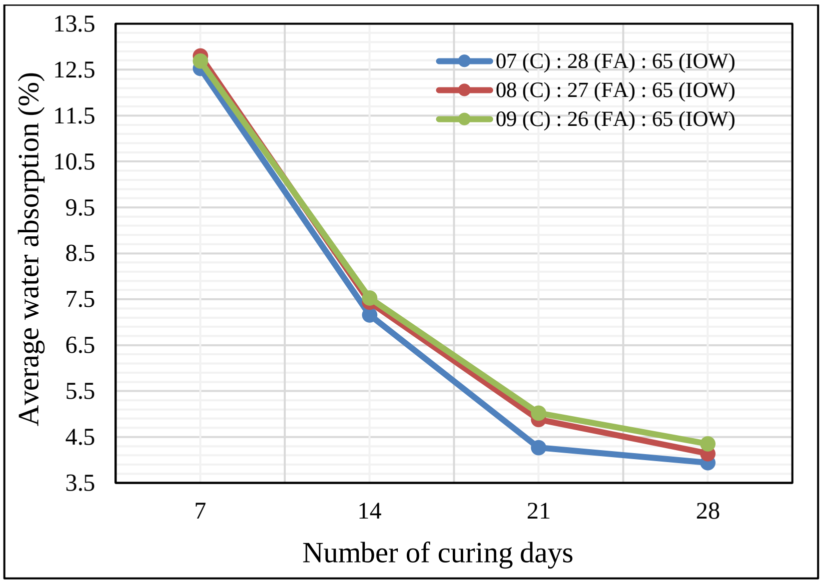


Fig. 6.66 Percentage of water absorption vs. number of curing days

6.8.6 Compressive strength and water absorption of bricks prepared with cement content 7 %, 8 % and 9% (Sample – 5, JLK-YRD)

The results of compressive strength of bricks prepared with cement content of 7 %, 8 % and 9 % and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % is given in Table 6.40. Figure 6.67 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-5. From the results obtained (Table 6.40), it was observed that with cement content 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing as in all the previous cases. However, with 9 % of cement content, the minimum required strength was obtained with 21 days of curing and above.

Figure 6.38 shows a plot of water absorption percentage of the bricks vs. number of curing days for Sample-5. From Table 6.41, it was observed that bricks prepared with cement ratio 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per IS Standards for all the days of curing period.

Table 6.40 Compressive strength of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.71	0.79	0.83	0.97	1.97	2.10	2.35	2.85	2.10	2.68	3.50	3.98
S2	0.68	0.77	0.80	0.95	2.01	2.13	2.40	2.90	2.17	2.75	3.56	4.01
S3	0.73	0.75	0.89	0.99	1.95	2.15	2.38	2.88	2.15	2.70	3.49	4.10
S4	0.70	0.71	0.91	1.00	1.98	2.09	2.36	2.91	2.08	2.69	3.58	3.95
S5	0.69	0.73	0.85	1.04	2.00	2.10	2.42	2.87	2.19	2.72	3.54	4.05
Average compressive strength (MPa)	**0.70**	**0.75**	**0.86**	**0.99**	**1.98**	**2.11**	**2.38**	**2.88**	**2.14**	**2.71**	**3.53**	**4.02**

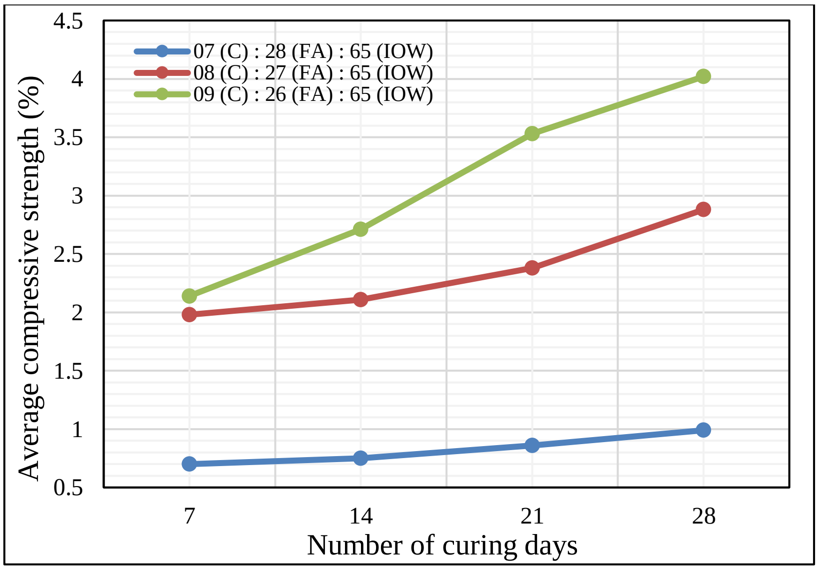


Fig. 6.67 Compressive strength vs. number of curing days

Table 6.41 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	12.97	6.88	5.79	4.25	13.09	7.50	5.98	4.50	13.29	7.68	6.19	4.60
S2	13.01	6.90	5.75	4.19	13.19	7.55	6.10	4.49	13.24	7.73	6.25	4.58
S3	12.99	6.78	5.77	4.21	13.15	7.45	6.05	4.41	13.30	7.69	6.21	4.63
S4	13.04	6.80	5.71	4.27	13.17	7.53	6.03	4.45	13.26	7.71	6.20	4.65
S5	13.00	6.92	5.69	4.20	13.10	7.51	6.09	4.47	13.22	7.70	6.23	4.59
Average water absorption (%)	**13.00**	**6.86**	**5.74**	**4.22**	**13.14**	**7.51**	**6.05**	**4.46**	**13.26**	**7.70**	**6.22**	**4.61**

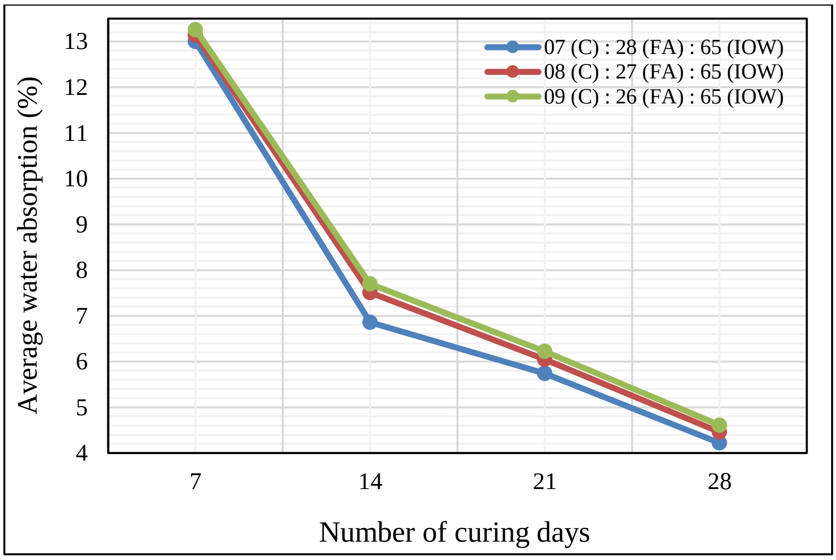


Fig. 6.68 Percentage of water absorption vs. number of curing days

6.8.7 Compressive strength and water absorption of bricks prepared with cement content 7 %, 8 % and 9 % (Sample – 9, RMK)

Bricks were prepared with 7 %, 8 % and 9 % of cement content, and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 %. The compressive strength results obtained for different curing period are given in Table 6.42. Figure 6.69 shows a plot of compressive strength of the bricks vs. number of curing days for Sample-9. From the results obtained (Table 6.42), it was observed that with cement content 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing as in all the previous cases. However, with 9 % of cement content, the minimum required strength was obtained with 21 days of curing and above.

Figure 6.70 shows a plot of water absorption percentage of the bricks vs. number of curing days for Sample-9. From Table 6.43, it was observed that bricks prepared with cement ratio 7 %, 8 % and 9 % will satisfy the percentage of water absorption limit as per IS Standards (< 20 % when immersed in water for 24 hrs.) for all the days of curing period.

Table 6.42 Compressive strength of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)											
S1	0.69	0.76	0.89	1.09	2.62	2.70	2.81	2.90	2.85	2.94	3.54	4.59
S2	0.65	0.74	0.85	1.07	2.61	2.75	2.79	2.88	2.90	2.88	3.45	4.57
S3	0.71	0.79	0.91	0.98	2.69	2.77	2.85	3.00	2.81	2.91	3.59	4.55
S4	0.67	0.82	0.90	0.95	2.63	2.69	2.83	2.95	2.87	2.93	3.51	4.50
S5	0.70	0.85	0.83	1.05	2.65	2.72	2.80	2.99	2.85	2.89	3.50	4.47
Average compressive strength (MPa)	**0.68**	**0.79**	**0.88**	**1.03**	**2.64**	**2.73**	**2.82**	**2.94**	**2.86**	**2.91**	**3.52**	**4.54**

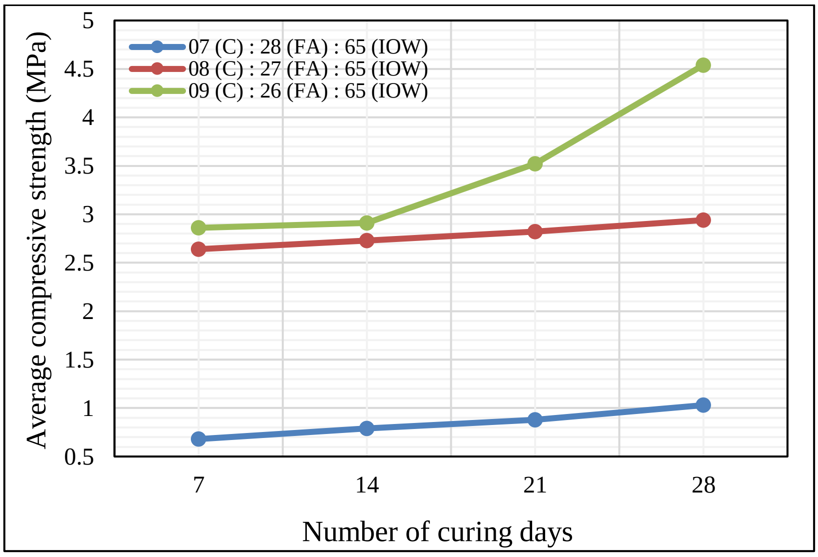


Fig. 6.69 Compressive strength vs. number of curing days

Table 6.43 Water absorption percentage of bricks prepared with cement ratio 7 %, 8 % and 9 % (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)												
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)											
S1	12.74	6.79	5.05	4.05	12.97	6.95	5.24	4.35	13.15	7.29	5.45	4.67
S2	12.65	6.77	5.09	4.10	12.99	7.00	5.35	4.27	13.20	7.25	5.56	4.61
S3	12.69	6.75	5.15	4.08	13.01	6.80	5.20	4.30	13.17	7.30	5.65	4.69
S4	12.71	6.71	5.13	4.12	12.95	6.85	5.37	4.29	13.21	7.33	5.60	4.65
S5	12.70	6.70	5.10	4.09	13.03	6.90	5.18	4.25	13.24	7.35	5.59	4.70
Average water absorption (%)	**12.70**	**6.74**	**5.10**	**4.09**	**12.99**	**6.90**	**5.27**	**4.29**	**13.19**	**7.30**	**5.57**	**4.66**

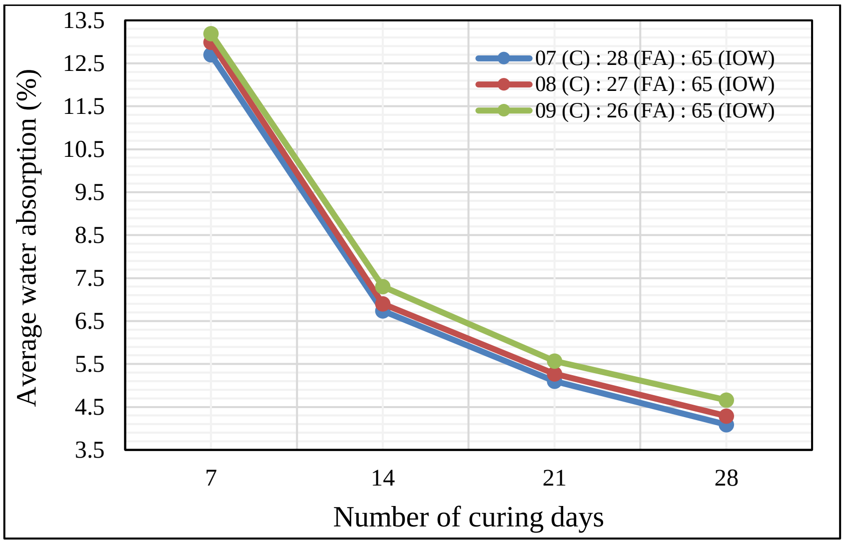


Fig. 6.70 Percentage of water absorption vs. number of curing days

6.9 Results of Brick Density

The results of density of bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days for a particular sample (Sample – 1) are given in Table 6.44. A plot of variation in density with respect to number of curing days for the same sample is shown from Figure 6.71 to Figure 6.76. From Table 6.44 and Figure 6.71 to Figure 6.76 it is observed that, there is decrease in density of bricks with increase in curing period which is mainly due to loss in moisture from the bricks with increase in curing days. It was also observed that there is decrease in brick density with increase in percentage of fly ash in the bricks which is mainly attributed due to very low density of fly ash compared to that of cement. A maximum density of 1.98 g/cm^3 with mix ratio 10 % cement and 90 % IOW and a minimum density of 1.48 g/cm^3 with mix ratio 10 % cement, 25 % fly ash and 65 % IOW was observed.

Similar trend in brick density was observed with all other sample locations for curing period 7, 14, 21 and 28 days.

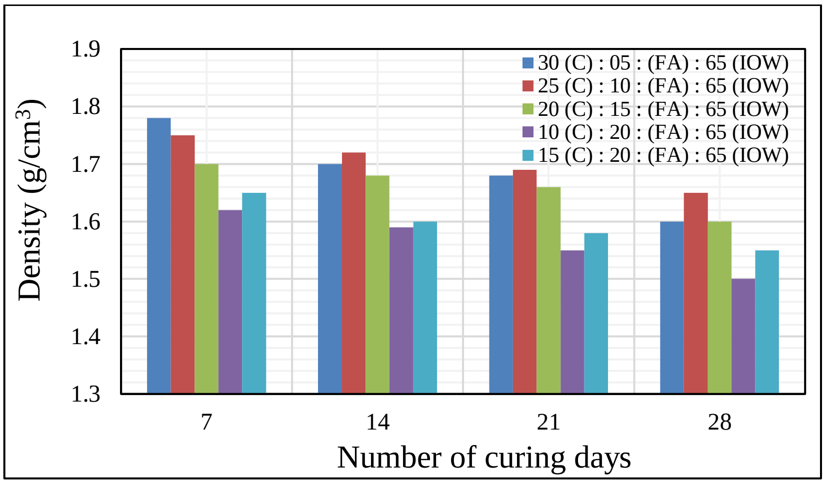


Fig. 6.71 Density vs. number of curing days with 65 % IOW

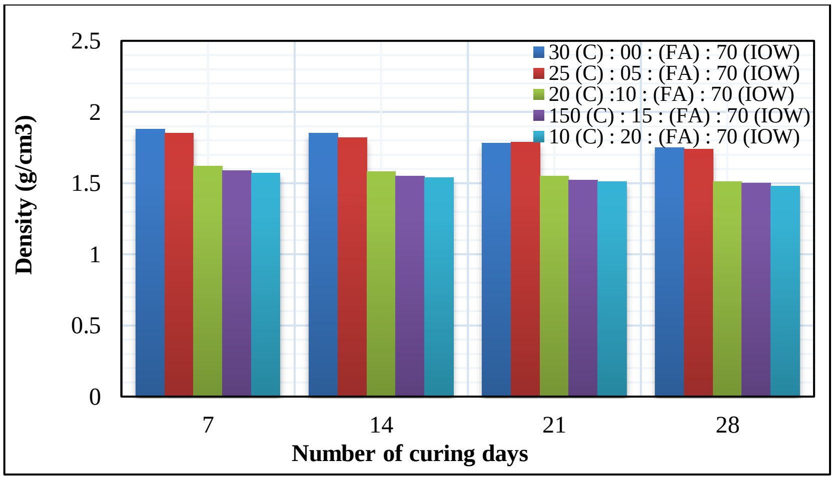


Fig. 6.72 Density vs. number of curing days with 70 % IOW

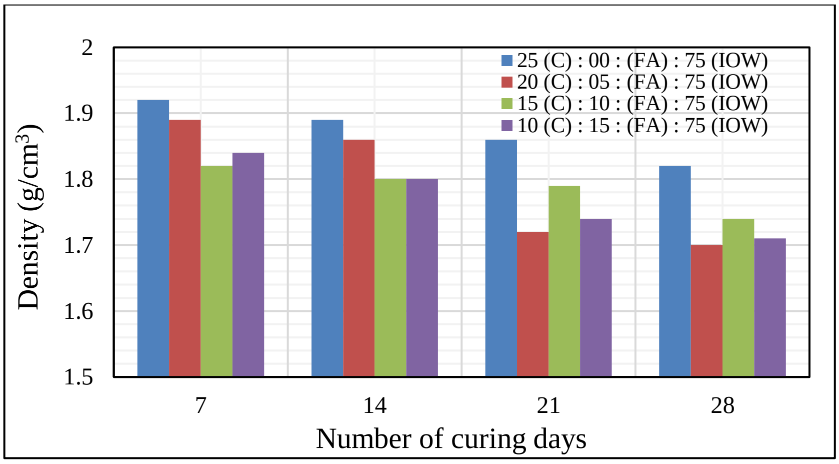


Fig. 6.73 Density vs. number of curing days with 75 % IOW

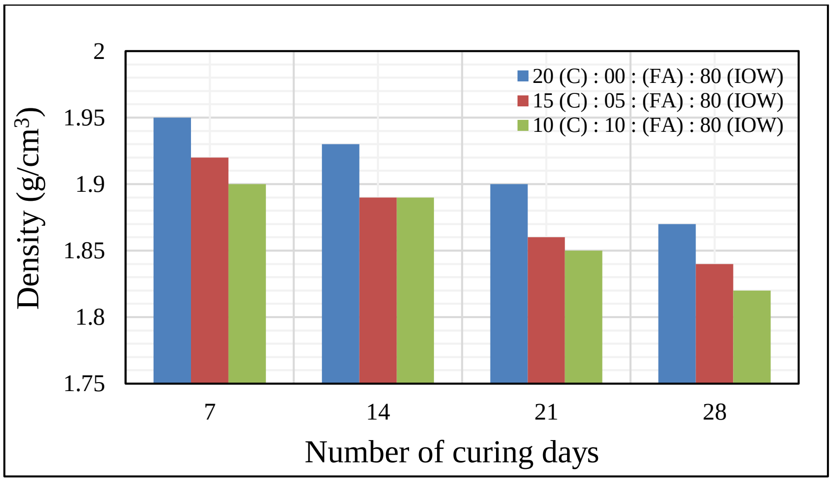


Fig. 6.74 Density vs. number of curing days with 80 % IOW

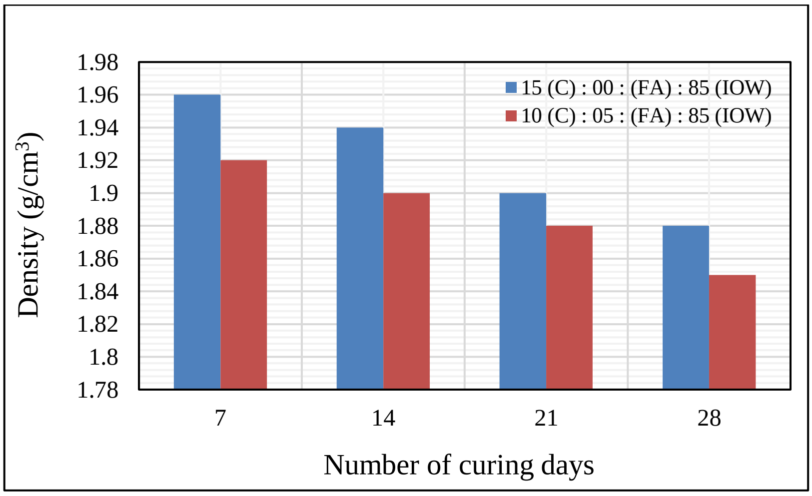


Fig. 6.75 Density vs. number of curing days with 85 % IOW

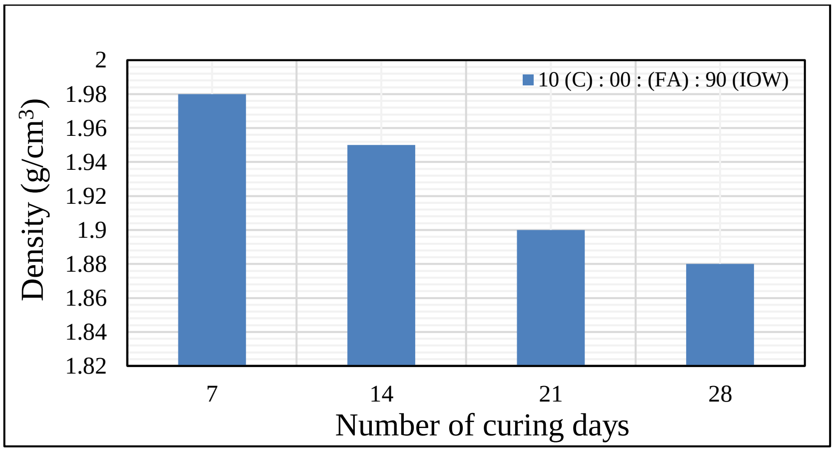


Fig. 6.76 Density vs. number of curing days with 90 % IOW

Table 6.44 Results of brick density prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D				10:25:65 (C:FA:IOW) (D)			
Curing days	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Average Density (g/cm^3)	1.78	1.70	1.68	1.60	1.75	1.72	1.69	1.65	1.70	1.68	1.66	1.60	1.65	1.60	1.58	1.55	1.62	1.59	1.55	1.50
	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
	1.88	1.85	1.78	1.75	1.85	1.82	1.79	1.74	1.62	1.58	1.55	1.51	1.59	1.55	1.52	1.50	1.57	1.54	1.51	1.48
	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)				---			
	1.92	1.89	1.86	1.82	1.89	1.86	1.72	1.70	1.82	1.80	1.79	1.74	1.84	1.80	1.74	1.71	---			
	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)				---							
	1.95	1.93	1.90	1.87	1.92	1.89	1.86	1.84	1.90	1.89	1.85	1.82	---							
	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)				---											
	1.96	1.94	1.90	1.88	1.92	1.90	1.88	1.85	---											
	10:00:90 (C:FA:IOW) (A)				---															
	1.98	1.95	1.90	1.88	---															

6.10 MASS OF BRICKS – WITH AND WITHOUT FLY ASH

6.10.1 Bricks With Fly ash

Bricks prepared with mix ratio of 65 % IOW, 12.5 % cement and 22.5 % fly ash is shown in Figure 6.77 and the mass obtained for different curing days are given in Table 6.45.

Fig. 6.77 Bricks with 65% IOW, 12.5% cement and 22.5% fly ash

6.10.2 Bricks Without Fly ash

Bricks prepared with mix ratio 87.5 % IOW and 12.5 % cement (without fly ash) are shown in Figure 6.78 and the mass obtained for different curing period are given in Table 6.45.

Fig. 6.78 Bricks with 87.5 % IOW and 12.5 % cement

The bricks prepared with 65 % IOW, 12.5 % cement and 22.5 % fly ash were compared with the bricks prepared with 87.5 % IOW and 12.5 % cement (without fly ash). From Table 6.45, it is observed that there is a significant change in mass. The average increase in mass observed was 0.4863 kg for bricks prepared without fly ash compared to bricks prepared with fly ash. The results clearly indicate the usefulness of using fly ash in preparing bricks from the point of view of reducing the mass of bricks.

Table 6.45 Difference in mass of bricks prepared with fly ash and without fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)		
Proportion of material	12.5:22.5:65 (C:FA:IOW) **(with fly ash)**	12.5:00:87.5 (C:FA:IOW) **(without fly ash)**
Brick	Weight of bricks (kg)	
S1	2.3750	2.8585
S2	2.3740	2.8548
S3	2.3726	2.8684
S4	2.3732	2.8620
S5	2.3755	2.8585
Average Weight (kg)	2.3741	2.8604

6.11 IOW BRICK VIS-À-VIS BURNT CLAY BRICK – COST

A survey was carried out with regard to cost of clay brick in different parts of the Karnataka. The results of the survey indicated that the cost of burnt clay bricks (uncompressed) varies from ₹ 5 to ₹ 8 per brick, in different places of Karnataka state.

6.11.1 Cost of Burnt Clay Bricks

There are two types of fired bricks are available in the market - ordinary bricks and compressed bricks. In general, the average cost of ordinary burnt clay brick (uncompressed) is ₹ 6.00 and that of compressed brick is ₹ 15. However, the compressive strength of ordinary bricks are much below 3.5 MPa and hence the bricks prepared in this study are compared only with that of fired compressed bricks, which fulfils the requirement of IS standards.

6.11.2 Cost Estimation of Prepared IOW Bricks

The procedure for cost estimation of prepared IOW bricks is as given below:

The cost of iron ore waste (IOW) was not considered, as the iron ore waste is a waste material for mine owners and is present in abundance in the mine. However, the transportation cost of IOW from the mine to NITK was considered and is ₹ 10,000/-, similarly the cost of fly ash was not considered as it is a waste product generated in power plants. Only the cost of transportation of fly ash was considered which is ₹ 600/-.

Total bricks prepared = 1,800

(Though the total bricks prepared were 1800, for this study only 315 bricks were used)

Fly ash cost (transportation) = ₹ 600/-

IOW cost (transportation cost) = ₹ 10,000/-

Total cost of fly ash and IOW = ₹ 10,600/-

Therefore, cost of one brick = ₹ 10600 ÷ 1800 = ₹ 5.89

Total amount of cement used in experimentation = 505 kg

Total cost of cement = ₹ 4,160/-

Therefore, the cost of cement / kg = ₹ 8.24

A. Bricks prepared with 30 % cement

Total No. of bricks prepared using 30 % cement = 30

Total amount of cement used for preparing 30 bricks = 15.3 kg

Therefore, amount spent on cement for preparing 30 bricks = ₹ 126.07

Cost of cement incurred on single brick = ₹ 4.202

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 4.202 + ₹ 5.89 = ₹ 10.09

B. Bricks prepared with 25 % cement

Total No. of bricks prepared using 25 % cement = 45

Total amount of cement used for preparing 45 bricks = 18.0 kg

Therefore, amount spent on cement for preparing 45 bricks = ₹ 148.32

Cost of cement incurred on single brick = ₹ 3.296

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 3.296 + ₹ 5.89 = ₹ 9.186

C. Bricks prepared with 20 % cement

Total No. of bricks prepared using 20 % cement = 60

Total amount of cement used for preparing 60 bricks = 20.4 kg

Therefore, amount spent on cement for preparing 60 bricks = ₹ 168.10

Cost of cement incurred on single brick = ₹ 2.80

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 2.80 + ₹ 5.89 = ₹ 8.69

D. Bricks prepared with 15 % cement

Total No. of bricks prepared using 15 % cement = 75

Total amount of cement used for preparing 75 bricks = 17.4 kg

Therefore, amount spent on cement for preparing 75 bricks = ₹ 143.376

Cost of cement incurred on single brick = ₹ 1.912

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 1.912 + ₹ 5.89 = ₹ 7.802

E. Bricks prepared with 10 % cement

Total No. of bricks prepared using 10 % cement = 90

Total amount of cement used for preparing 90 bricks = 14.7 kg

Therefore, amount spent on cement for preparing 90 bricks = ₹ 121.13

Cost of cement incurred on single brick = ₹ 1.346

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 1.346 + ₹ 5.89 = ₹ 7.236

F. Bricks prepared with 5 % cement

Total No. of bricks prepared using 5 % cement = 15

Total amount of cement used for preparing 15 bricks = 1.28 kg

Therefore, amount spent on cement for preparing 15 bricks = ₹ 10.55

Cost of cement incurred on single brick = ₹ 0.703

Therefore, total cost of preparing one single brick (cement + fly ash + IOW) = ₹ 0.703 + ₹ 5.89 = ₹ 6.593

In the above calculations labour cost has been ignored as all the bricks were prepared by the scholar himself. However, even by adding the labour cost into the total manufacturing cost of bricks, the cost of prepared bricks would be very much economical when it is compared to that of commercial bricks available in the market.

6.12 CLOSURE

Iron ore waste samples were collected from the iron ore mine belonging to M/S. SMIORE from nine different locations and were tested for its chemical analysis. The results of the chemical analysis indicated that out of nine samples collected, Fe_2O_3 percentage was 30 and above in three of the sample locations. These three iron ore waste samples with 30 and above percentage of Fe_2O_3 could be used in near future as ore by upgrading them. Hence out of nine, only six samples were considered for the process of brick making.

The prepared bricks were tested for its physico-mechanical properties as per IS standards. Table 6.46 gives the required compressive strength as per BIS guidelines achieved with minimum days of curing with different combination of IOW such as 65 %, 70 %, 75 %, 80 %, 85 % and 90 %, for all six locations. In all the cases, the minimum required strength of 3.5 MPa was achieved with different curing periods.

The results of water absorption test indicates that all the bricks prepared in this investigation with different mix ratios were all well within the standards prescribed by BIS standards i.e. water absorption was less than 20 % when immersed in water for 24 hrs duration.

The results of density obtained from bricks prepared with iron ore waste, cement and fly ash in different proportions with different curing periods of 7, 14, 21 and 28 days revealed that the density of the brick reduces with increase in the curing period. It was also observed that the density of the bricks decreases with increase in percentage of fly ash.

The results of compressive strength and water absorption of bricks prepared with cement content of 7 %, 8 % and 9 % and fly ash being varied from 28 %, 27 % and 26 % respectively with IOW being kept constant at 65 % reveal that with cement content of 7 % and 8 %, the minimum required compressive strength could not be achieved for all the days of curing i.e., 7, 14, 21 and 28 days. Bricks with 9 % cement content, the minimum required strength was obtained with 14 days of curing for Sample-2 and Sample-3, with 21 days of curing for Sample-5 and Sample-9 and with 28 days of curing for Sample-1 and Sample-4. Hence, in general, it may be concluded that even bricks with 9 % cement will meet the required IS standards with 28 days of curing. It was also observed that bricks prepared with cement content of 9 % also meet the percentage of water absorption limit as per IS Standards (< 20% when immersed in water for 24 hrs.) for all the days of curing period.

The bricks prepared with 65 % IOW, 12.5 % cement and 22.5 % fly ash were compared with the bricks prepared with 87.5 % IOW and 12.5 % cement (without fly ash). A significant change in mass was observed. The average increase in mass was 0.4863 kg for bricks prepared without fly ash compared to bricks prepared with fly ash. Hence use of fly ash in preparing such bricks is recommended as it reduces the mass of the bricks.

It was also found that the bricks prepared with 30 % cement, 20 % cement, 15 % cement and 10 % cement costs ₹ 10, ₹ 9.20, ₹ 8.70, ₹ 7.80 and ₹ 7.20 per brick (excluding profit) respectively, which is substantially below the cost of fired compressed bricks available in the market (costing ₹ 15 per brick).

Table 6.46 Required compressive strength as per BIS guidelines achieved with minimum days of curing

Sample location	Compressive strength (MPa)	Water absorption (%)	Ratio (C:FA:IOW)	Curing days
1	4.14	6.48	10:25:65	21
	3.61	6.66	10:20:70	14
	3.80	6.67	10:15:75	21
	3.65	5.29	10:10:80	28
	3.53	5.24	10:05:85	28
	3.63	5.03	10:00:90	28
2	5.10	5.79	10:25:65	21
	3.80	7.23	10:20:70	14
	5.56	7.13	10:15:75	14
	4.43	7.13	10:10:80	14
	4.71	7.07	10:05:85	14
	3.91	7.01	10:00:90	14
3	3.54	11.68	10:25:65	07
	3.61	6.81	10:20:70	14
	3.71	6.89	10:15:75	14
	3.76	5.93	10:10:80	14
	4.35	11.45	10:05:85	07
	3.90	4.96	10:00:90	21
4	5.18	4.71	10:25:65	28
	3.91	13.66	10:20:70	07
	5.94	7.90	10:15:75	14
	5.78	6.09	10:10:80	21
	4.28	6.10	10:05:85	21
	4.82	6.08	10:00:90	21
5	4.08	6.38	10:25:65	21
	3.60	7.79	10:20:70	14
	3.68	7.73	10:15:75	14
	4.64	7.68	10:10:80	14
	4.52	7.69	10:05:85	14
	3.79	7.61	10:00:90	14
9	4.16	13.47	10:25:65	07
	4.39	13.31	10:20:70	07
	6.17	13.36	10:15:75	07
	4.70	7.43	10:10:80	14
	3.63	13.27	10:05:85	07
	5.71	4.63	10:00:90	28

7.0 REGRESSION MODELLING

7.1 INTRODUCTION

To obtain applicable and practical ratios of brick ingredients, it is necessary to model the strength of the brick. Multiple regression analysis is widely used for modelling and analysing the experimental results. Regression is the determination of statistical relationship between two or more variables. It is the statistical method to deal with the formulation of mathematical model depicting the relationship amongst the variables which can be used for the purpose of prediction of values of dependent or response variables, given the values of predictor or independent variable(s).

The analysis concerning the relationship is known as multiple correlation and equations describing such relationships are called as multiple regression equations. The compressive strength of the bricks can be predicted by multiple regression modelling, the statistical methodology used to relate the ratios of the ingredients used to make bricks.

In order to establish the predictive model among the parameters obtained in this research work, multiple regression and analysis of variance (ANOVA) techniques were used. For modelling and analysis a free ware software for windows Peppier 0.7.9 was used. It is a program for the analysis of sampled data.

7.2 MULTIPLE REGRESSION ANALYSIS AND ANOVA TECHNIQUE

The laboratory experimental results were used to model the various responses using multiple regression method by using a linear fit among the responses and corresponding significant parameters. The performance of the model depends on a large number of factors that act and interact in a complex manner. When the predictor variables in a multiple regression model are interrelated or are dependent on each other, a multi-collinearity problem exists and hinders the ability to assess the importance of a predictor variable.

The regression modelling of compressive strength of the iron ore waste bricks is influenced by the ratio of cement, fly ash and iron ore waste. ANOVA was carried out to find which input parameter significantly affects the desired response. To facilitate experiment and measurement, three important predictor variables are considered in the present study. They are cement (C), fly ash (F) and iron ore waste (IOW).

The responses considered are compressive strength and water absorption of bricks after 1, 2, 3 and 4 weeks (7 days, 14 days, 21 days and 28 days). The mathematical models for the physico-mechanical properties with parameters under consideration can be represented by equation 7.1.

$$y = f(x_1, x_2, x_3, \dots \dots ..) + \epsilon \tag{7.1}$$

where, y is the response and x1, x2, x3 are the independent process variables and ∑ is fitting error. A linear model ‘f’ can be written as:

$$f = b_0 + \sum_{i=1}^{n} bi\ xi + \epsilon \tag{7.2}$$

where, b_i represents the linear effect of x_i.

Individual responses were modelled by using multiple regression analysis. The coefficient table lists the estimated coefficients for all the predicators. P-value determines the observed relationship between response and the predictors, which indicates whether it is statistically significant or not. Once the p-value is less than α level (To test the significance, one need to set a risk level called the alpha level. In most of the cases, “the rule of thumb” is to set the alpha level at 0.05, i.e. 95 % confidence interval), then the association is statistically significant and hence the model was selected.

In this work, different ratios of cement, fly ash and iron ore waste were selected to check the compressive strength of bricks and water absorption. The test was carried out using iron ore from 6 different locations, namely Seelu kola (SK), Kanniga marada kola (KMK), Nerru kola (NK), Ankammnal, Jaldi kolla (JLK) and Rama kola (RMK).

Ratios of cement, iron ore waste and fly ash were used as independent variables to obtain compressive strength and water absorption of bricks.

7.3 SELECTION OF SAMPLES FOR MODELLING

Results of compressive strength and water absorption for different curing period i.e. one week, two weeks, three weeks and four weeks (7 days, 14 days, 21 days and 28 days) were used for the modelling purpose.

7.4 REGRESSION MODELS

7.4.1 Multiple Regression Models of Samples Cured for 7 days

Multiple regression models to predict compressive strength and water absorption using experimental values are taken after one week of making bricks.

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-1, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample- 1) = $- 0.4432 + 0.3076\ C + 0.0012\ F + 0.0008\ IOW$

where,

C = Percentage of cement

F = Percentage of fly ash

IOW = Percentage of iron ore waste

Multiple regression model to predict compressive strength of bricks made up from sample location-2, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample- 2) = $0.5217 + 0.1679\ C + 0.0213\ F + 0.0120\ IOW$

Multiple regression model to predict compressive strength of bricks made up from sample location-3, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample- 3) = $0.3824 + 0.3213\ C + 0.02129\ F + 0.0032\ IOW$

Multiple regression model to predict compressive strength of bricks made up from sample location-4, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample- 4) = $- 0.6533 + 0.2759\ C + 0.0413\ F + 0.0036\ IOW$

Multiple regression model to predict compressive strength of bricks made up from sample location-5, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample 5) = $0.6013 + 0.1927\ C + 0.0354\ F + 0.0021\ IOW$

Multiple regression model to predict compressive strength of bricks made up from sample location-9, with 7 days curing is:

$CS_{\text{7 days curing}}$ (Sample- 9) = $2.7553 + 0.2913\ C - 0.0388\ F + 0.0016\ IOW$

Significance of regression coefficients for estimation of compressive strength is given in Table 7.1(a). This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.1 b gives the model summary for dependent variable.

Table 7.1(a) Analysis of variance (ANOVA) for the linear model for estimation of compressive strength for all the samples which were cured for 7 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	77.64	25.88	7.27	0.00
2	Linear	3	21.15	7.05	34.21	0.00
3	Linear	3	83.87	27.96	43.75	0.00
4	Linear	3	57.23	19.08	8.61	0.00
5	Linear	3	28.47	9.49	27.11	0.00
9	Linear	3	81.23	27.08	4.40	0.02

Table 7.1(b) Model summary for dependent variable (compressive strength of all the samples which were cured for 7 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.76	0.58	0.53	1.89
2	0.93	0.87	0.85	0.45
3	0.94	0.89	0.88	0.80
4	0.79	0.62	0.57	1.49
5	0.91	0.84	0.82	0.59
9	0.67	0.45	0.39	2.48

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-1, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 1) = 14.6238 - 0.1236 C - 0.0837 F + 0.0018 IOW

Multiple regression model to predict water absorption of bricks made up from sample location-2, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 2) = 12.6184 + 0.0317 C + 0.0129 F + 0.0031 IOW

Multiple regression model to predict water absorption of bricks made up from sample location-3, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 3) = 11.0236 + 0.0329 C + 0.0148 F + 0.0016 IOW

Multiple regression model to predict water absorption of bricks made up from sample location-4, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 4) = 13.3386 + 0.0230 C + 0.0185 F + 0.0027 IOW

Multiple regression model to predict water absorption of bricks made up from sample location-5, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 5) = 12.9353 + 0.0313 C + 0.0112 F + 0.0018 IOW

Multiple regression model to predict water absorption of bricks made up from sample location-9, with 7 days curing is:

$WA_{\text{7 days curing}}$ (Sample- 9) = - 2036.3848 + 97.6214 C + 117.1140 F + 0.0017 IOW

Significance of regression coefficients for estimation of water absorption is given in Table 7.2a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.2 b gives the model summary for dependent variable.

Table 7.2(a) Analysis of variance (ANOVA) for the linear model for estimation of water absorption for all the samples which were cured for 7 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	6.68	2.23	12.19	0.00
2	Linear	3	0.45	0.15	256.09	0.00
3	Linear	3	0.75	0.25	233.81	0.00
4	Linear	3	0.36	0.12	192.13	0.00
5	Linear	3	0.61	0.20	287.11	0.00
9	Linear	3	0.81	0.35	287.72	0.01

Table 7.2(b) Model summary for dependent variable (water absorption of all the samples which were cured for 7 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.83	0.70	0.66	0.43
2	0.99	0.98	0.98	0.02
3	0.99	0.98	0.97	0.03
4	0.00	0.97	0.97	0.02
5	0.99	0.98	0.98	0.03
9	0.27	0.08	- 0.03	3201.51

7.4.2 Multiple Regression Models of Samples Cured for 14 days

Multiple regression models to predict compressive strength and water absorption using experimental values taken after two weeks of making bricks.

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-1, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 1) = - 0.4216 + 0.3265 C + 0.0268 F + 0.0036 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-2, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 2) = 5.0208 + 0.0724 C - 0.0864 F + 0.0017 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-3, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 3) = - 0.8958 + 0.3918 C + 0.0653 F + 0.0012 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-4, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 4) = - 0.4238 + 0.3164 C + 0.0857 F + 0.0032 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-5, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 5) = 3.7753 + 0.1135 C - 0.0614 F + 0.0022 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-9, with 14 days curing is:

$CS_{14\ days\ curing}$ (Sample- 9) = - 1.0844 + 0.5719 C + 0.1048F + 0.0013 IOW

Significance of regression coefficients for estimation of compressive strength is given in Table 7.3a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.3 b gives the model summary for dependent variable.

Table 7.3(a) Analysis of variance (ANOVA) for the linear model for estimation of compressive strength for all the samples which were cured for 14 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	83.07	27.69	8.76	0.00
2	Linear	3	16.06	5.35	5.35	0.01
3	Linear	3	117.27	39.09	30.52	0.00
4	Linear	3	67.44	22.48	8.22	0.00
5	Linear	3	20.32	6.77	6.86	0.00
9	Linear	3	242.82	80.94	25.94	0.00

Table 7.3(b) Model summary for dependent variable (compressive strength of all the samples which were cured for 14 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.79	0.62	0.58	1.78
2	0.71	0.50	0.44	1.00
3	0.92	0.85	0.83	1.13
4	0.78	0.61	0.56	1.65
5	0.75	0.56	0.51	0.99
9	0.91	0.83	0.81	1.77

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-1, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 1) = 8.3492 + 0.0248 C - 0.0123 F + 0.0018 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-2, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 2) = 6.8042 + 0.0219 C - 0.0148 F + 0.0047 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-3, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 3) = 4.8441 + 0.0883 C - 0.0649 F + 0.0072 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-4, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 4) = 7.6403 + 0.0228 C - 0.0142 F + 0.0140 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-5, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 5) = 7.3349 + 0.0324 C - 0.0149 F + 0.0042 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-9, with 14 days curing is:

$WA_{\text{14 days curing}}$ (Sample- 9) = 7.1169 + 0.0342 C - 0.0113 F + 0.0030 IOW

Significance of regression coefficients for estimation of water absorption is given in Table 7.4a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.4 b gives the model summary for dependent variable.

Table 7.4(a) Analysis of variance (ANOVA) for the linear model for estimation of water absorption for all the samples which were cured for 14 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	0.17	0.06	6.40	0.00
2	Linear	3	0.36	0.12	144.10	0.00
3	Linear	3	5.44	1.81	42.47	0.00
4	Linear	3	0.33	0.11	72.87	0.00
5	Linear	3	0.50	0.17	43.29	0.00
9	Linear	3	0.49	0.16	216.31	0.00

Table 7.4(b) Model summary for dependent variable (water absorption of all the samples which were cured for 14 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.74	0.55	0.49	0.09
2	0.98	0.96	0.96	0.03
3	0.94	0.89	0.88	0.21
4	0.97	0.93	0.92	0.04
5	0.94	0.89	0.88	0.06
9	0.99	0.98	0.97	0.03

7.4.3 Multiple Regression Models of Samples Cured for 21 days

Multiple regression models to predict compressive strength and water absorption using experimental values taken after two weeks of making bricks.

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-1, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 1) = - 1.1433 + 0.3881 C + 0.0513 F + 0.0014 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-2, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 2) = 1.8751 + 0.3163 C + 0.0488 F + 0.0011 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-3, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 3) = - 0.9377 + 0.4529 C + 0.0981 F + 0.0013 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-4, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 4) = 4.2086 + 0.2365 C - 0.0513 F + 0.0054 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-5, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 5) = 3.3776 + 0.1558 C - 0.0235 F + 0.0035 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-9, with 21 days curing is:

$CS_{\text{21 days curing}}$ (Sample- 9) = - 1.3352 + 0.6183 C + 0.1165 F + 0.0018 IOW

Significance of regression coefficients for estimation of compressive strength is given in Table 7.5 a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.5 b gives the model summary for dependent variable.

Table 7.5(a) Analysis of variance (ANOVA) for the linear model for estimation of compressive strength for all the samples which were cured for 21 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	115.76	38.59	15.49	0.00
2	Linear	3	77.32	25.77	47.41	0.00
3	Linear	3	150.08	5.03	34.10	0.00
4	Linear	3	59.82	19.94	4.15	0.02
5	Linear	3	21.77	7.26	13.80	0.00
9	Linear	3	282.62	94.21	32.04	0.00

Table 7.5(b) Model summary for dependent variable (compressive strength of all the samples which were cured for 21 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.86	0.74	0.71	1.58
2	0.95	0.90	0.89	0.74
3	0.93	0.86	0.85	1.21
4	0.66	0.44	0.37	2.19
5	0.85	0.72	0.69	0.73
9	0.93	0.86	0.84	1.71

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-1, with 21 days curing is:

$\text{WA}_{\text{21 days curing}}$ (Sample- 1) = 6.6443 + 0.0148 C - 0.0132 F + 0.0014 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-2, with 21 days curing is:

$\text{WA}_{\text{21 days curing}}$ (Sample- 2) = 5.4979 + 0.0214 C + 0.0014 F + 0.0052 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-3, with 21 days curing is:

$\text{WA}_{\text{21 days curing}}$ (Sample- 3) = 4.6217 + 0.0434 C + 0.0169 F + 0.0043 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-4, with 21 days curing is:

$\text{WA}_{\text{21 days curing}}$ (Sample- 4) = 5.9166 + 0.0248 C + 0.0004 F + 0.0032 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-5, with 21 days curing is:

$WA_{21\ days\ curing}$ (Sample- 5) = 5.6907 + 0.0366 C + 0.0148 F + 0.0034 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-9, with 21 days curing is:

$WA_{21\ days\ curing}$ (Sample- 9) = 5.3829 + 0.0309 C + 0.0169 F + 0.0052 IOW

Significance of regression coefficients for estimation of water absorption is given in Table 7.6a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.6 b gives the model summary for dependent variable.

Table 7.6(a) Analysis of variance (ANOVA) for the linear model for estimation of water absorption for all the samples which were cured for 21 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	0.09	0.03	5.84	0.01
2	Linear	3	0.30	0.10	41.21	0.00
3	Linear	3	0.93	0.31	134.18	0.00
4	Linear	3	0.33	0.11	97.34	0.00
5	Linear	3	0.68	0.23	79.58	0.00
9	Linear	3	0.56	0.19	28.28	0.00

Table 7.6(b) Model summary for dependent variable (water absorption of all the samples which were cured for 21 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.72	0.52	0.47	0.07
2	0.94	0.89	0.87	0.05
3	0.98	0.96	0.96	0.05
4	0.97	0.95	0.94	0.03
5	0.97	0.94	0.93	0.05
9	0.92	0.84	0.82	0.08

7.4.4 Multiple Regression Models of Samples Cured for 28 days

Multiple regression models to predict compressive strength and water absorption using experimental values taken after two weeks of making bricks.

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-1, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 1) = - 2.1607 + 0.4832 C + 0.1257 F + 0.0019 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-2, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 2) = 1.7032 + 0.3518 C + 0.0643 F + 0.0012 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-3, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 3) = - 2.4236 + 0.5718 C + 0.1311 F + 0.0015 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-4, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 4) = 0.7656 + 0.5314 C + 0.0716 F + 0.0049 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-5, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 5) = 3.6288 + 0.2014 C - 0.0469 F + 0.0023 IOW

Multiple regression model to predict compressive strength (CS) of bricks made up from sample location-9, with 28 days curing is:

$\text{CS}_{\text{28 days curing}}$ (Sample- 9) = - 0.0468 + 0.5713 C + 0.0918 F + 0.0018 IOW

Significance of regression coefficients for estimation of compressive strength is given in Table 7.5a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.5b gives the model summary for dependent variable.

Table 7.7(a) Analysis of variance (ANOVA) for the linear model for estimation of compressive strength for all the samples which were cured for 28 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	164.66	54.89	19.76	0.00
2	Linear	3	90.19	30.06	52.54	0.00
3	Linear	3	238.50	79.50	37.37	0.00
4	Linear	3	216.25	72.08	11.50	0.00
5	Linear	3	43.67	14.56	34.96	0.00
9	Linear	3	253.59	84.53	30.44	0.00

Table 7.7(b) Model summary for dependent variable (compressive strength of all the samples which were cured for 28 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.89	0.79	0.76	1.67
2	0.95	0.91	0.90	0.76
3	0.94	0.88	0.86	1.46
4	0.83	0.68	0.65	2.50
5	0.93	0.87	0.85	0.65
9	0.92	0.85	0.83	1.67

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-1, with 28 days curing is:

$WA_{\text{28 days curing}}$ (Sample- 1) = 5.1104 + 0.0133 C + 0.0048 F + 0.0019 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-2, with 28 days curing is:

$WA_{\text{28 days curing}}$ (Sample- 2) = 6.5409 - 0.0783 C - 0.0049 F + 0.0034 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-3, with 28 days curing is:

$WA_{\text{28 days curing}}$ (Sample- 3) = 3.7594 + 0.0492 C + 0.0206 F + 0.0019 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-4, with 28 days curing is:

$WA_{28\ \text{days curing}}$ (Sample- 4) = 4.3520 + 0.0214 C + 0.0092 F + 0.0009 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-5, with 28 days curing is:

$WA_{28\ \text{days curing}}$ (Sample- 5) = 4.1567 + 0.0314 C + 0.0014 F + 0.0057 IOW

Multiple regression model to predict water absorption (WA) of bricks made up from sample location-9, with 28 days curing is:

$WA_{28\ \text{days curing}}$ (Sample- 9) = 4.4401 + 0.0155 C + 0.0117 F + 0.0031 IOW

Significance of regression coefficients for estimation of water absorption is given in Table 7.8a. This ANOVA table represents mean square (MS), sum of squares (SS), F-value and p-value associated with factors. Table 7.8 b gives the model summary for dependent variable.

Table 7.8(a) Analysis of variance (ANOVA) for the linear model for estimation of water absorption for all the samples which were cured for 28 days

Sample location No.	Source of variations	Degree of freedom	Sum of squares	Mean square	F- value	p-value
1	Linear	3	0.09	0.03	4.48	0.02
2	Linear	3	3.07	1.02	0.26	0.85
3	Linear	3	0.99	0.33	235.47	0.00
4	Linear	3	0.32	0.11	38.95	0.00
5	Linear	3	0.72	0.24	161.72	0.00
9	Linear	3	0.22	0.07	1.37	0.29

Table 7.8(b) Model summary for dependent variable (water absorption of all the samples which were cured for 28 days)

Sample location No.	R	R^2	Adjusted R^2	Standard error
1	0.68	0.46	0.39	0.08
2	0.22	0.05	0.07	1.98
3	0.99	0.98	0.98	0.04
4	0.94	0.88	0.87	0.05
5	0.98	0.97	0.96	0.04
9	0.45	0.20	0.11	0.23

7.4.5 Abstract of Multiple Regression Model to Predict Compressive Strength

Table 7.9 gives the abstract of the equations of multiple regression model to predict compressive strength of bricks for different days of curing for all the sample locations.

Table 7.9 Multiple regression model to predict compressive strength

Multiple Regression Model to Predict Compressive Strengths (C – Cement, F- Fly ash, IOW- Iron ore waste, CS – Compressive strength)				
Curing Period	7 days	14 days	21 days	28 days
Sample 1	CS (MPa) = - 0.4432 + 0.3076 C + 0.0012 F + 0.0008 IOW	CS (MPa) = - 0.4216 + 0.3265 C + 0.0268 F + 0.0036 IOW	CS (MPa) = - 1.1433 + 0.3881 C + 0.0513 F + 0.0014 IOW	CS (MPa) = - 2.1607 + 0.4832 C + 0.1257 F + 0.0019 IOW
Sample 2	CS (MPa) = 0.5217 + 0.1679 C + 0.0213 F + 0.0120 IOW	CS (MPa) = 5.0208 + 0.0724 C - 0.0864 F + 0.0017 IOW	CS (MPa) = 1.8751 + 0.3163 C + 0.0488 F + 0.0011 IOW	CS (MPa) = 1.7032 + 0.3518 C + 0.0643 F + 0.0012 IOW
Sample 3	CS (MPa) = 0.3824 + 0.3213 C + 0.02129 F + 0.0032 IOW	CS (MPa) = - 0.8958 + 0.3918 C + 0.0653 F + 0.0012 IOW	CS (MPa) = - 0.9377 + 0.4529 C + 0.0981 F + 0.0013 IOW	CS (MPa) = - 2.4236 + 0.5718 C + 0.1311 F + 0.0015 IOW
Sample 4	CS (MPa) = - 0.6533 + 0.2759 C + 0.0413 F + 0.0036 IOW	CS (MPa) = - 0.4238 + 0.3164 C + 0.0857 F + 0.0032 IOW	CS (MPa) = 4.2086 + 0.2365 C - 0.0513 F + 0.0054 IOW	CS (MPa) = 0.7656 + 0.5314 C + 0.0716 F + 0.0049 IOW
Sample 5	CS (MPa) = 0.6013 + 0.1927 C + 0.0354 F + 0.0021 IOW	CS (MPa) = 3.7753 + 0.1135 C - 0.0614 F + 0.0022 IOW	CS (MPa) = 3.3776 + 0.1558 C - 0.0235 F + 0.0035 IOW	CS (MPa) = 3.6288 + 0.2014 C - 0.0469 F + 0.0023 IOW
Sample 9	CS (MPa) = 2.7553 + 0.2913 C - 0.0388 F + 0.0016 IOW	CS (MPa) = - 1.0844 + 0.5719 C + 0.1048F + 0.0013 IOW	CS (MPa) = - 1.3352 + 0.6183 C + 0.1165 F + 0.0018 IOW	CS (MPa) = - 0.0468 + 0.5713 C + 0.0918 F + 0.0018 IOW

7.4.6 Abstract of Multiple Regression Model to Predict Percentage of Water Absorption

Table 7.10 gives the equations of multiple regression model to predict water absorption percentage of bricks for different days of curing period for all the sample locations.

7.5 PERFORMANCE PREDICTION OF DERIVED MODELS

The coefficient of correlation between the measured and predicted values is a good indicator to check the prediction performance of the model. However, in this study, Root Mean Square Error (RMSE) indices were calculated to compare the performance of the prediction capacity of predictive models developed (Alvareez and Babuska, 1999; Finol et al., 2001; Gokceoglu 2002; Yilmaz and Yuksek, 2008; Yilmaz and Yuksek, 2009; Yilmaz and Kaynar, 2011).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y - y')^2}$$

where, y and y' are the measured and predicted values, respectively. If the RMSE is 0, then the model will be excellent.

Table 7.10 Multiple regression model to predict percentage of water absorption

Multiple Regression Model to Predict Water Absorption Percentage (C – Cement, F- Fly ash, IOW- Iron ore waste, WA – Water absorption)				
Curing Period	7 days	14 days	21 days	28 days
Sample 1	WA = 14.6238 - 0.1236 C - 0.0837 F + 0.0018 IOW	WA = 8.3492 + 0.0248 C - 0.0123 F + 0.0018 IOW	WA = 6.6443 + 0.0148 C - 0.0132 F + 0.0014 IOW	WA = 5.1104 + 0.0133 C + 0.0048 F + 0.0019 IOW
Sample 2	WA = 12.6184 + 0.0317 C + 0.0129 F + 0.0031 IOW	WA = 6.8042 + 0.0219 C - 0.0148 F + 0.0047 IOW	WA = 5.4979 + 0.0214 C + 0.0014 F + 0.0052 IOW	WA = 6.5409 - 0.0783 C - 0.0049 F + 0.0034 IOW
Sample 3	WA = 11.0236 + 0.0329 C + 0.0148 F + 0.0016 IOW	WA = 4.8441 + 0.0883 C - 0.0649 F + 0.0072 IOW	WA = 4.6217 + 0.0434 C + 0.0169 F + 0.0043 IOW	WA = 3.7594 + 0.0492 C + 0.0206 F + 0.0019 IOW
Sample 4	WA = 13.3386 + 0.0230 C + 0.0185 F + 0.0027 IOW	WA = 7.6403 + 0.0228 C - 0.0142 F + 0.0140 IOW	WA = 5.9166 + 0.0248 C + 0.0004 F + 0.0032 IOW	WA = 4.3520 + 0.0214 C + 0.0092 F + 0.0009 IOW
Sample 5	WA = 12.9353 + 0.0313 C + 0.0112 F + 0.0018 IOW	WA = 7.3349 + 0.0324 C - 0.0149 F + 0.0042 IOW	WA = 5.6907 + 0.0366 C + 0.0148 F + 0.0034 IOW	WA = 4.1567 + 0.0314 C + 0.0014 F + 0.0057 IOW
Sample. 9	WA = - 2036.3848 + 97.6214 C + 117.1140 F + 0.0017 IOW	WA = 7.1169 + 0.0342 C - 0.0113 F + 0.0030 IOW	WA = 5.3829 + 0.0309 C + 0.0169 F + 0.0052 IOW	WA = 4.4401 + 0.0155 C + 0.0117 F + 0.0031 IOW

Mean Absolute percentage Error (MAPE) which is a measure of accuracy in a fitted series value was also used to check the prediction performances of the models (Gokceoglu, 2002; Yilmaz and Kaynar, 2011). MAPE usually expresses accuracy as a percentage.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{A_i - P_i}{A_i}\right| X\ 100$$

where, *Ai* is the actual value and P_i is the predicted value. Lower values of MAPE, indicate that there will be a better correlation between predicted values and experimental results.

Using the developed regression models for bricks, performance prediction indices for training as well as test data were calculated and are given in Table 7.11 to 7.16. From the table it was observed that, for bricks, MAPE values for test data for compressive strength are 18.28443, 19.24573, 21.05789 and 22.35536 for curing of 7, 14, 21 and 28 days respectively for sample location-1. The MAPE values for water absorption are 4.63194, 4.39553, 6.38121 and 8.13882 for curing of 7, 14, and 21 and 28 days respectively for sample-1, which indirectly explains the reliability of the predicted models for bricks. The experimental results of compressive strength and water absorption obtained which are included in Annexure V were used to test the data for prediction indices of regression model.

Table 7.11 Performance prediction indices of regression model for bricks (Sample-1)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	0.7432	0.8638	1.2356	1.0091	0.52362	0.13680	0.8356	0.71082
	MAPE	10.1406	16.3292	14.3721	17.0385	1.1503	1.2976	2.7789	3.1496
Test data	RMSE	1.21992	1.98451	2.00754	1.41767	0.82827	0.41657	1.14967	0.90757
	MAPE	18.28443	19.24573	21.05789	22.35536	4.63194	4.39553	6.38121	8.13882

Table 7.12 Performance prediction indices of regression model for bricks (Sample-2)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	0.6384	0.9421	0.7230	0.6567	0.8662	0.1368	0.9805	0.9612
	MAPE	10.1409	12.683	13.2605	1.8942	1.9683	2.0568	3.5629	4.8634
Test data	RMSE	1.95604	2.20825	1.83166	2.32489	1.89859	0.12734	1.87872	1.97845
	MAPE	19.30247	20.6234	19.54941	19.1143	3.12364	5.21799	7.85843	8.00143

Table 7.13 Performance prediction indices of regression model for bricks (Sample-3)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	1.6843	2.8472	3.6647	4.1086	0.0419	0.2369	0.7894	0.3661
	MAPE	7.8643	8.4138	8.9902	9.4057	2.1435	3.1287	1.1893	3.4638
Test data	RMSE	3.76627	4.18687	5.3217	6.35069	0.60019	3.21645	1.17786	0.4441
	MAPE	14.1922	13.9923	17.9561	18.5923	3.96694	4.16808	2.43561	4.89388

Table 7.14 Performance prediction indices of regression model for bricks (Sample-4)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	1.4326	1.6782	0.9492	1.6328	0.21468	0.41352	0.91438	0.12356
	MAPE	7.8012	9.1128	9.3762	10.8432	1.2561	0.94678	2.45988	0.82354
Test data	RMSE	2.61219	3.8586	4.73504	7.95939	1.47175	0.98482	1.56859	0.64949
	MAPE	12.0848	19.612	19.7926	27.7101	1.15169	1.32323	3.25768	1.50726

Table 7.15 Performance prediction indices of regression model for bricks (Sample-5)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	1.94381	1.7402	2.18113	2.8969	0.04852	0.12568	0.39662	0.24569
	MAPE	8.1384	9.4564	10.1148	10.0039	2.8698	2.9985	4.2138	5.1236
Test data	RMSE	2.211813	2.21566	2.94611	3.4611	0.45231	0.29862	0.57281	0.35829
	MAPE	11.6173	10.6605	12.9932	11.4109	3.36475	3.08937	5.01789	6.15346

Table 7.16 Performance prediction indices of regression model for bricks (Sample-9)

		Compressive strength				Water absorption			
No. of curing days		7	14	21	28	7	14	21	28
Training data	RMSE	2.36104	3.8924	2.93022	2.21346	0.21789	0.38273	0.92461	0.5434
	MAPE	15.30042	14.7891	11.3694	12.4493	0.2738	3.9993	4.8344	4.3247
Test data	RMSE	4.4779	7.48058	8.11158	7.94699	0.34263	0.4274	1.02909	0.89275
	MAPE	17.8163	28.5921	28.5873	25.7553	4.32829	4.47202	6.6165	5.24961

7.6 CLOSURE

In this chapter, the experimental data were used to develop regression models for predicting compressive strength and percentage of water absorption of prepared bricks. Prediction indices were calculated for the developed models for comparing the performance of the developed model with the experimental results.

8.0 IMPACT OF CHEMICAL COMPOSITION OF BRICKS ON ITS COMPRESSIVE STRENGTH

8.1 CHEMICAL COMPOSITION OF MATERIALS USED IN PREPARING BRICKS

The results of chemical analysis of iron ore waste, fly ash and cement was already discussed and given in Chapter 6, Table 6.13 and Figure 6.11.It was found that, the major chemical composition in IOW, fly ash and cement are SiO_2, Al_2O_3 and Fe_2O_3. Table 8.1 gives the percentage of SiO_2, Al_2O_3 and Fe_2O_3 in fly ash, cement and IOW of different locations which is also shown in Figure 8.1. From Table 8.1 and Figure 8.1 it is also seen that the mass percentage of S_iO_2 is highest in case of cement, fly ash and IOW. The mass percentage of Al_2O_3 varies from 10.44 to 34, the mass percentage of Fe_2O_3 varies from 6.47 to 27.24 whereas that of SiO_2 varies from 18.71 to 50.80 for fly ash, cement and IOW of all the six locations.

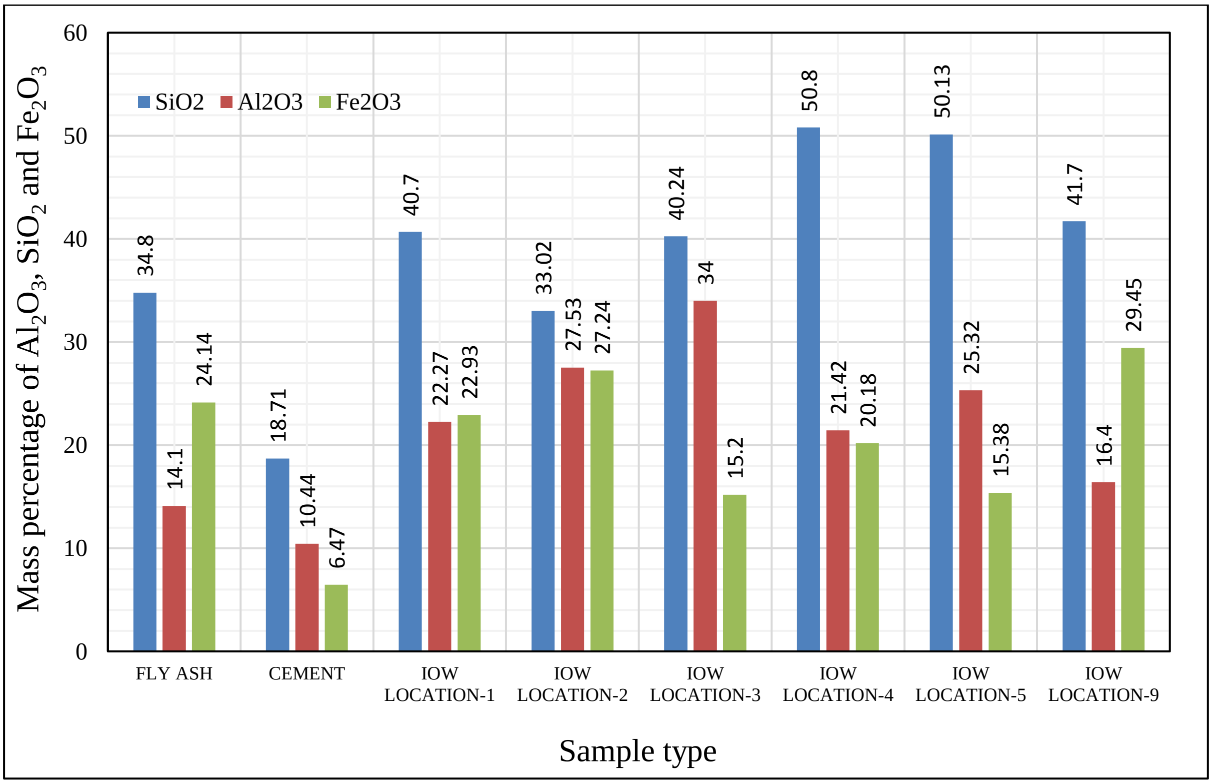


Fig. 8.1 Mass percentage of S_iO_2, Al_2O_3 and Fe_2O_3 of fly ash, cement and IOW

Table 8.1 Major chemical composition of fly ash, cement and IOW

Items	Major chemical composition (%)		
	SiO_2	Al_2O_3	Fe_2O_3
Fly ash	34.80	14.10	24.14
Cement	18.71	10.44	06.47
IOW, Sample Location-1	40.70	22.27	22.93
IOW, Sample Location-2	33.02	27.53	27.24
IOW, Sample Location-3	40.24	34.00	15.20
IOW, Sample Location-4	50.80	21.42	20.18
IOW, Sample Location-5	50.13	25.32	15.38
IOW, Sample Location-9	41.70	16.40	29.45

8.2 Total percentage of Al_2O_3, SiO_2 and Fe_2O_3 in a brick

To investigate the impact of major chemical composition of cement, fly ash and IOW for Sample location-1 to 5 and Sample location-9, the average mass of the bricks with 28 days of curing period were measured. The chemical compositions like total percentage of Al_2O_3, SiO_2 and Fe_2O_3 in a brick were observed through the output of Java program which was executed in NetBeans 8.1 IDE for all the mix ratios. This was done to avoid tedious and time consuming calculations over a calculator. The Flowchart of the computer program is shown in Figure 8.2 whereas the program output in the form of screen shot is shown in Figure 8.3. The methodology used for computation of percentage of Al_2O_3, SiO_2 and Fe_2O_3 in the computer program is given below:

Let the mass of the brick = m (kg.)

Let us assume that the brick has 10 % cement, 20 % fly ash and 70 % IOW

Then,

Mass of cement in a brick, C = $\frac{10}{100}$ kg.

Mass of fly ash in a brick, F = $\frac{20}{100}$ kg.

Mass of IOW in a brick, IOW = $\frac{70}{100}$ kg.

Let the percentage of Al_2O_3 in cement be, x %

Let the percentage of SiO_2 in cement be, y %

Let the percentage of Fe_2O_3 in cement be, z %

Then, in $\frac{10\,m}{100}$ kg. cement, The percentage of $Al_2O_3 = \frac{10\,m}{100}$ x $\frac{x}{100}$ kg.

The percentage of $SiO_2 = \frac{10\,m}{100}$ x $\frac{y}{100}$ kg.

The percentage of $Fe_2O_3 = \frac{10\,m}{100}$ x $\frac{z}{100}$ kg.

Let the percentage of Al_2O_3 in fly ash be, a %

Let the percentage of SiO_2 in fly ash be b, %

Let the percentage of Fe_2O_3 in fly ash be, c %

Then, in $\frac{20\,m}{100}$ kg. fly ash,

The percentage of $Al_2O_3 = \frac{20\,m}{100}$ x $\frac{a}{100}$ kg.

The percentage of $SiO_2 = \frac{20\,m}{100}$ x $\frac{b}{100}$ kg.

The percentage of $Fe_2O_3 = \frac{20\,m}{100}$ x $\frac{c}{100}$ kg.

Let the percentage of Al_2O_3 in IOW be, d %

Let the percentage of SiO_2 in IOW be, e %

Let the percentage of Fe_2O_3 in IOW be, f %

Then, in $\frac{70\,m}{100}$ kg. IOW,

The percentage of $Al_2O_3 = \frac{70\,m}{100}$ x $\frac{d}{100}$ kg.

The percentage of $SiO_2 = \frac{70\,m}{100}$ x $\frac{e}{100}$ kg.

The percentage of $Fe_2O_3 = \frac{70\,m}{100}$ x $\frac{f}{100}$ kg.

Total Al_2O_3 in a brick = $\left(\frac{10\,m}{100} \text{ x } \frac{x}{100} + \frac{20\,m}{100} \text{ x } \frac{a}{100} + \frac{70\,m}{100} \text{ x } \frac{d}{100}\right)$ kg.

Total SiO_2 in a brick = $\left(\frac{10\,m}{100} \text{ x } \frac{y}{100} + \frac{20\,m}{100} \text{ x } \frac{b}{100} + \frac{70\,m}{100} \text{ x } \frac{e}{100}\right)$ kg.

Total Fe_2O_3 in a brick = $\left(\frac{10\,m}{100} \text{ x } \frac{z}{100} + \frac{20\,m}{100} \text{ x } \frac{c}{100} + \frac{70\,m}{100} \text{ x } \frac{f}{100}\right)$ kg.

$$\textbf{Total \% of } \mathbf{Al_2O_3} \textbf{ in a brick} = \frac{\boldsymbol{Total\ of Al_2O_3\ in\ a\ brick\ (kg.)}}{\boldsymbol{Mass\ of\ brick\ (kg.)}}\ \mathbf{X\ 100}\ \%$$

$$\textbf{Total \% of } \mathbf{SiO_2} \textbf{ in a brick} = \frac{\boldsymbol{Total\ of SiO_2\ in\ a\ brick\ (kg.)}}{\boldsymbol{Mass\ of\ brick\ (kg.)}}\ \mathbf{X\ 100}\ \%$$

$$\textbf{Total \% of } \mathbf{Fe_2O_3} \textbf{ in a brick} = \frac{\boldsymbol{Total\ of\ Fe_2O_3\ in\ a\ brick\ (kg.)}}{\boldsymbol{Mass\ of\ brick\ (kg.)}}\ \mathbf{X\ 100}\ \%$$

The input to the developed program were mass of a brick; percentage of cement, fly ash and IOW; percentage of Al_2O_3, SiO_2 and Fe_2O_3 in cement, fly ash and IOW. The output of the developed program was total percentage of Al_2O_3, SiO_2 and Fe_2O_3 in a particular brick.

8.3 RESULTS AND ANALYSIS

The results of the percentage of Al_2O_3, SiO_2 and Fe_2O_3 in bricks prepared from all the six locations are given in Table 8.2 to Table 8.7.

Table 8.2 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-1)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
1	**30:05:65**	2.4402	18.31	33.81	18.05	11.69
	25:10:65	2.4368	18.50	34.61	18.94	11.20
	20:15:65	2.4360	18.68	35.42	19.82	10.81
	15:20:65	2.4355	18.86	36.22	20.70	10.55
	10:25:65	2.4340	19.04	37.03	21.59	4.46
	30:00:70	2.4450	18.72	34.1	17.99	11.59
	25:05:70	2.4410	18.90	34.91	18.88	8.69
	20:10:70	2.4385	19.09	35.71	19.76	6.94
	15:15:70	2.4365	19.27	36.52	20.64	4.47
	10:20:70	2.4355	19.45	37.32	21.53	3.84
	25:00:75	2.4475	19.31	35.20	18.82	11.94
	20:05:75	2.4445	19.50	36.01	19.70	9.47
	15:10:75	2.4425	19.68	36.81	20.58	8.38
	10:15:75	2.4395	19.86	37.62	21.47	4.45
	20:00:80	2.4480	19.90	36.30	19.64	5.79
	15:05:80	2.4472	20.09	37.11	20.52	5.49
	10:10:80	2.4455	20.27	37.91	21.41	3.65
	15:00:85	2.4475	20.50	37.40	20.46	5.32
	10:05:85	2.4458	19.57	36.17	20.20	3.53
	10:00:90	2.4482	21.09	38.50	21.28	3.63

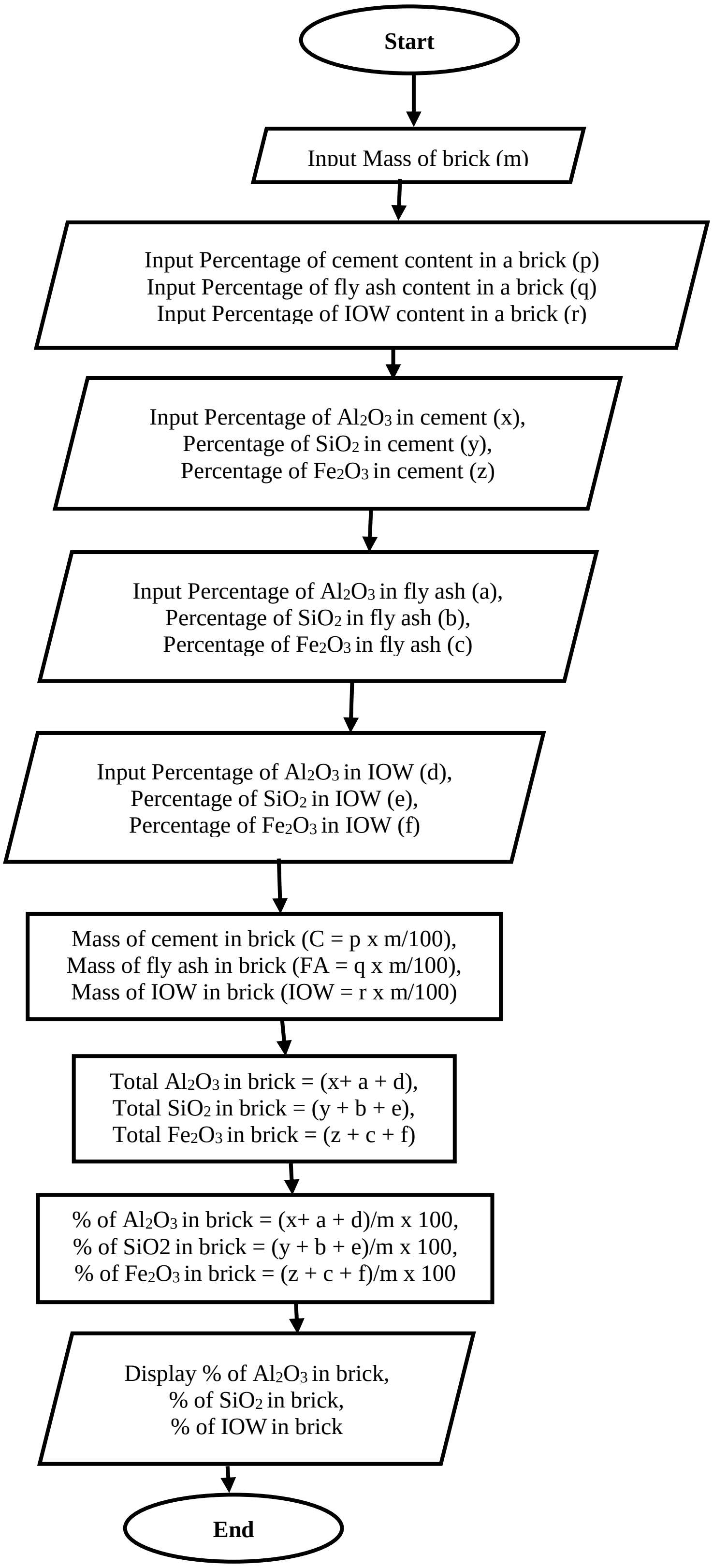
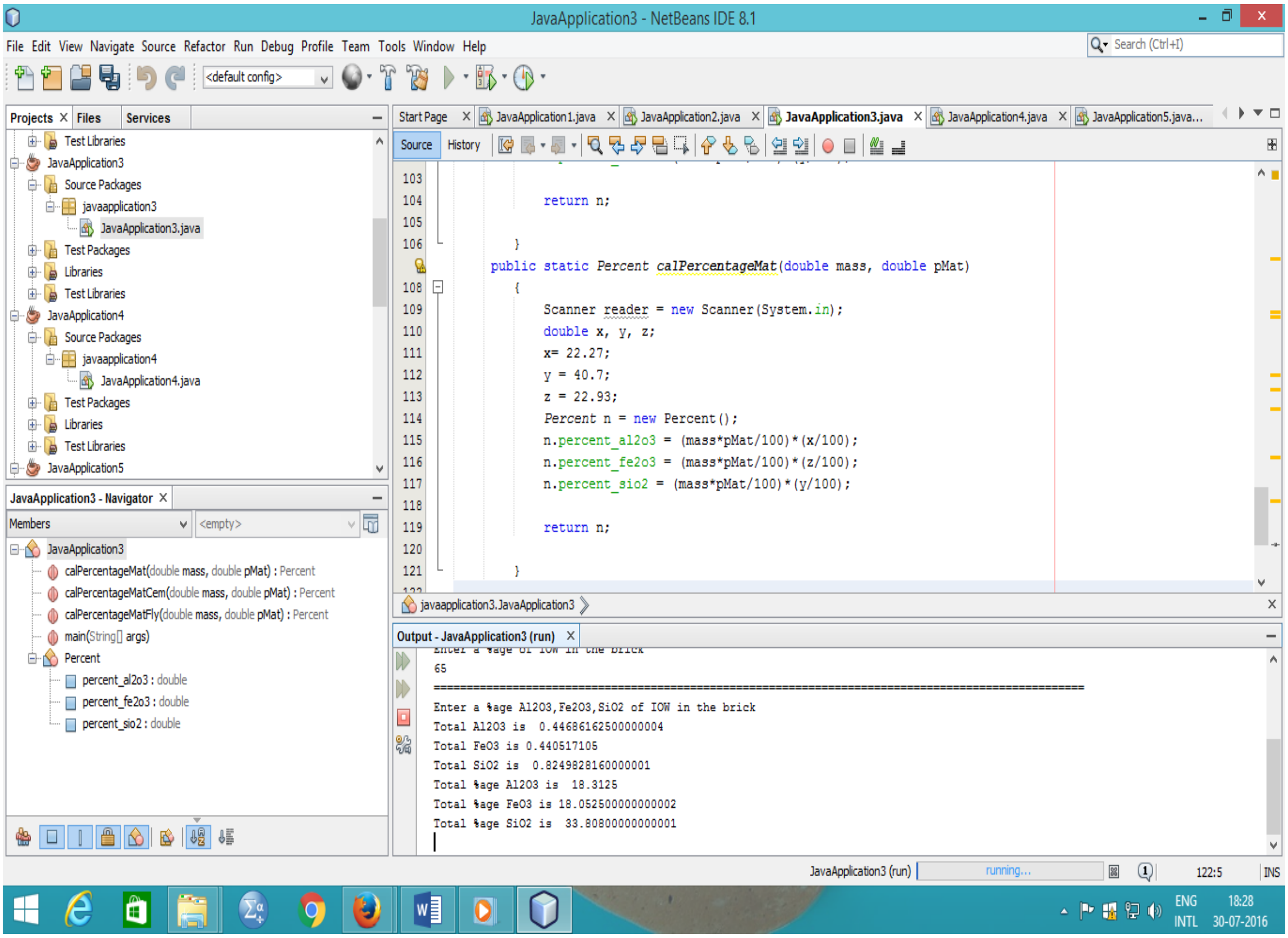


Fig. 8.2 Flow chart to find percentage of Al_2O_3, SiO_2 and Fe_2O_3 in brick



```java
            return n;

        }
    public static Percent calPercentageMat(double mass, double pMat)
        {
            Scanner reader = new Scanner(System.in);
            double x, y, z;
            x= 22.27;
            y = 40.7;
            z = 22.93;
            Percent n = new Percent();
            n.percent_al2o3 = (mass*pMat/100)*(x/100);
            n.percent_fe2o3 = (mass*pMat/100)*(z/100);
            n.percent_sio2 = (mass*pMat/100)*(y/100);

            return n;

        }
```

```
Enter a %age of IOW in the brick
65
========================================================================================================
Enter a %age Al2O3,Fe2O3,SiO2 of IOW in the brick
Total Al2O3 is  0.44686162500000004
Total FeO3 is 0.440517105
Total SiO2 is  0.824982816000001
Total %age Al2O3 is  18.3125
Total %age FeO3 is 18.052500000000002
Total %age SiO2 is  33.80800000000001
```

Fig. 8.3 Program output screen shot to find the total percentage of Al_2O_3, SiO_2 and Fe_2O_3 in a brick

Table 8.3 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-2)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
2	**30:05:65**	2.4490	21.73	28.82	20.85	11.05
	25:10:65	2.4455	21.91	29.62	21.74	9.35
	20:15:65	2.4435	22.10	30.43	22.62	8.84
	15:20:65	2.4398	22.28	31.23	23.50	8.22
	10:25:65	2.4366	22.46	32.03	24.39	5.40
	30:00:70	2.4462	22.40	28.73	21.01	12.31
	25:05:70	2.4424	22.59	29.53	21.89	11.02
	20:10:70	2.4401	22.77	30.34	22.78	10.45
	15:15:70	2.4387	22.95	31.14	23.66	7.94
	10:20:70	2.4365	23.14	31.95	24.54	6.70
	25:00:75	2.4470	23.26	29.44	22.05	10.06
	20:05:75	2.4459	23.44	30.25	22.93	9.36
	15:10:75	2.4445	23.62	31.05	23.81	7.92
	10:15:75	2.4405	23.81	31.86	24.70	6.70
	20:00:80	2.4490	24.11	30.16	23.09	8.96
	15:05:80	2.4481	24.30	30.96	23.97	8.08
	10:10:80	2.4469	24.48	31.77	24.85	5.37
	15:00:85	2.4495	24.97	30.87	24.97	6.55
	10:05:85	2.4478	23.77	30.03	23.77	5.46
	10:00:90	2.4502	25.82	31.59	25.16	4.15

Table 8.4 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-3)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
3	**30:05:65**	2.4462	25.94	33.51	13.03	16.49
	25:10:65	2.4449	26.12	34.31	13.91	15.52
	20:15:65	2.4428	26.30	35.12	14.80	11.12
	15:20:65	2.4311	26.49	35.92	15.68	7.59
	10:25:65	2.4302	26.67	36.73	16.56	4.92
	30:00:70	2.4475	26.93	33.78	12.58	14.41
	25:05:70	2.4457	27.12	34.59	13.46	12.59
	20:10:70	2.4436	27.30	35.39	14.35	11.40
	15:15:70	2.4321	27.48	36.19	15.23	10.75
	10:20:70	2.4300	27.66	37.00	16.12	4.94
	25:00:75	2.4482	28.11	34.86	13.02	9.29
	20:05:75	2.4468	28.29	35.66	13.90	8.40
	15:10:75	2.4449	28.48	36.47	14.78	6.43
	10:15:75	2.4429	28.66	37.27	15.67	6.13
	20:00:80	2.4497	29.29	35.93	13.45	7.75
	15:05:80	2.4491	29.47	36.74	14.34	6.88
	10:10:80	2.4477	29.65	37.54	15.22	5.18
	15:00:85	2.4506	30.47	37.01	13.89	5.87
	10:05:85	2.4497	28.95	35.80	14.01	5.06
	10:00:90	2.4517	31.64	38.09	14.33	4.16

Table 8.5 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-4)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
4	**30:05:65**	2.4435	17.76	40.37	16.27	17.09
	25:10:65	2.4420	17.94	41.18	17.15	10.55
	20:15:65	2.4408	18.13	41.98	18.03	10.02
	15:20:65	2.4378	18.31	42.79	18.92	8.81
	10:25:65	2.4345	18.49	43.59	19.80	5.18
	30:00:70	2.4469	18.13	41.17	16.07	18.69
	25:05:70	2.4455	18.31	41.98	16.95	16.59
	20:10:70	2.4429	18.49	42.78	17.83	15.75
	15:15:70	2.4400	18.68	43.59	18.72	12.38
	10:20:70	2.4360	18.86	44.39	19.60	8.86
	25:00:75	2.4479	18.68	42.78	16.75	12.34
	20:05:75	2.4463	18.86	43.58	17.64	9.86
	15:10:75	2.4435	19.04	44.39	18.52	8.07
	10:15:75	2.4405	19.22	45.19	19.40	11.93
	20:00:80	2.4490	19.22	44.38	17.44	11.92
	15:05:80	2.4482	19.41	45.19	18.33	8.65
	10:10:80	2.4445	19.59	45.99	19.23	6.14
	15:00:85	2.4500	19.77	45.99	18.12	7.70
	10:05:85	2.4491	18.89	44.25	18.00	5.17
	10:00:90	2.4510	20.32	47.59	18.81	5.79

Table 8.6 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-5)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
5	**30:05:65**	2.4469	20.30	39.94	13.15	9.28
	25:10:65	2.4449	20.48	40.74	14.03	8.25
	20:15:65	2.4406	20.66	41.55	14.91	6.56
	15:20:65	2.4370	20.84	42.35	15.80	5.45
	10:25:65	2.4330	21.03	43.16	16.68	4.37
	30:00:70	2.4477	20.86	40.70	12.71	10.14
	25:05:70	2.4469	21.04	41.51	13.59	8.16
	20:10:70	2.4448	21.22	42.31	14.47	7.47
	15:15:70	2.4395	21.41	43.12	15.36	6.35
	10:20:70	2.4355	21.59	43.92	16.24	6.06
	25:00:75	2.4474	21.60	42.28	13.15	8.91
	20:05:75	2.4454	21.78	43.08	14.04	6.96
	15:10:75	2.4439	21.97	43.88	14.92	6.03
	10:15:75	2.4411	22.15	44.69	15.80	5.34
	20:00:80	2.4497	22.34	43.85	13.60	8.75
	15:05:80	2.4475	22.53	44.65	14.48	7.16
	10:10:80	2.4410	22.71	45.46	15.37	4.64
	15:00:85	2.4511	23.09	45.42	14.04	6.33
	10:05:85	2.4487	22.01	43.72	14.16	5.72
	10:00:90	2.4519	23.83	46.99	14.49	4.30

Table 8.7 Percentage of Al_2O_3, SiO_2 and of Fe_2O_3 in bricks (Sample location-9)

Sample location No.	Mix ratio (C:FA:IOW)	Avg. Mass of brick (kg)	Total % of Al_2O_3 in a brick	Total % of SiO_2 in a brick	Total % of Fe_2O_3 in a brick	Compressive strength of a brick for 28 days of curing (MPa)
9	**30:05:65**	2.4448	14.50	34.46	22.29	17.61
	25:10:65	2.4432	14.68	35.26	23.17	15.98
	20:15:65	2.4395	14.86	36.07	24.06	14.47
	15:20:65	2.4350	15.05	36.87	24.94	11.87
	10:25:65	2.4317	15.23	37.68	25.82	5.56
	30:00:70	2.4470	14.61	34.80	22.56	15.40
	25:05:70	2.4445	14.80	35.61	23.44	12.40
	20:10:70	2.4412	14.98	36.41	24.32	11.81
	15:15:70	2.4380	15.16	37.22	25.21	10.01
	10:20:70	2.4345	15.34	38.02	26.09	5.66
	25:00:75	2.4479	14.91	35.95	23.71	14.34
	20:05:75	2.4445	15.09	36.76	24.59	13.50
	15:10:75	2.4424	15.28	37.56	25.47	13.04
	10:15:75	2.4384	15.46	38.37	26.36	7.42
	20:00:80	2.4482	15.21	37.10	24.85	11.34
	15:05:80	2.4466	15.39	37.91	25.74	10.39
	10:10:80	2.4439	15.57	38.71	26.62	4.97
	15:00:85	2.4490	15.51	38.25	26.00	7.88
	10:05:85	2.4455	14.87	36.97	25.41	5.72
	10:00:90	2.4525	15.80	39.40	27.15	5.71

As the aim of this investigation was to find out the impact of major chemical constituents in a brick on its compressive strength, hence using Table 8.2 to Table 8.7, careful study was carried out to see the variation of a particular chemical constituent with compressive strength keeping the other two chemical constituents constant. For instance, Table 8.8 was arrived at by careful study of Table 8.2 and Table 8.5. It was found that for constant value of $Al_2O_3 \approx 19$ % and $Fe_2O_3 \approx 19$ %, there is variation in SiO_2 with compressive strength. A plot of total percentage of SiO_2 vs. compressive strength i.e., data of Table 8.8 is shown in Figure 8.4. From Figure 8.4 it is observed that there is no correlation between the total percentages of SiO_2 present in a brick with its compressive strength.

Similarly, Table 8.9 was arrived at by careful study of Table 8.7. It was found that for constant value of $SiO_2 \approx 38$ % and $Fe_2O_3 \approx 26$ %, there is variation in Al_2O_3 with compressive strength. A plot of total percentage of Al_2O_3 vs. compressive strength i.e., data of Table 8.9 is shown in Figure 8.5. From Figure 8.5 it is observed that there is no correlation between the total percentages of Al_2O_3 present in a brick with its compressive strength.

Table 8.8 Variation of SiO_2 with compressive strength ($Al_2O_3 \approx 19$ % $Fe_2O_3 \approx 19$ %)

Total percentage of SiO_2	Compressive strength (MPa)
34.61	11.20
34.91	8.69
35.20	11.94
43.59	5.18
43.59	12.38
44.39	8.86
44.39	8.07
45.19	11.93
45.19	6.14

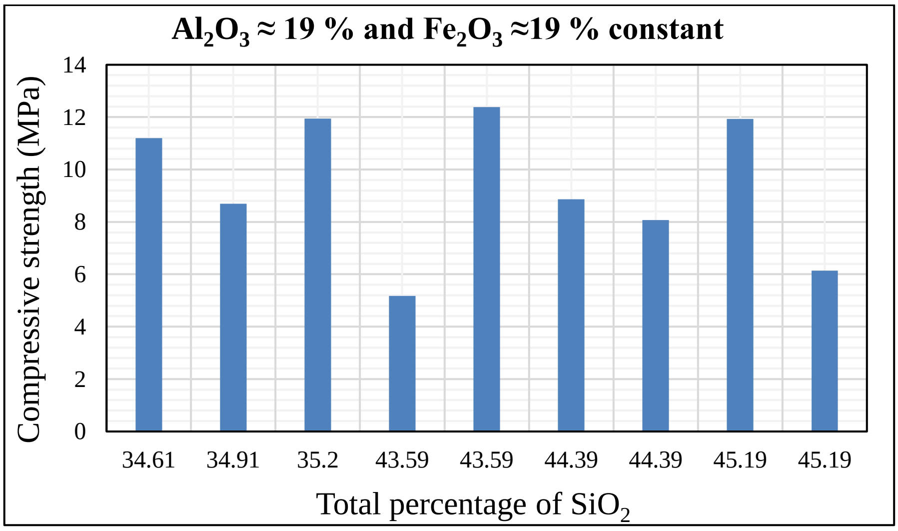


Fig. 8.4 Total percentage of SiO_2 vs. compressive strength

Table 8.9 Variation of Al_2O_3 with compressive strength ($SiO_2 \approx 38$ % and $Fe_2O_3 \approx 26$ %)

Total percentage of Al_2O_3	Compressive strength (MPa)
15.23	5.56
15.28	13.04
15.34	5.66
15.39	10.39
15.46	7.42
15.51	7.88

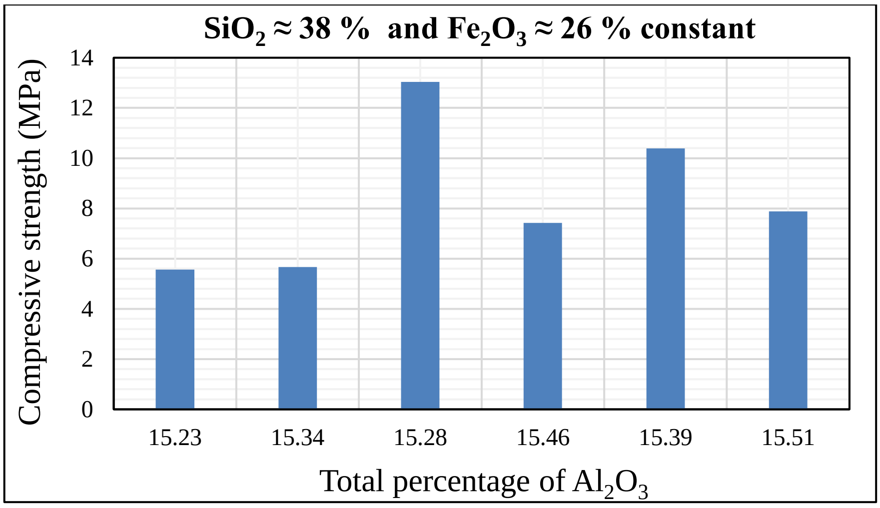


Fig. 8.5 Total percentage of Al_2O_3 vs. compressive strength

In a similar fashion, Table 8.10 was arrived at by careful study of Table 8.3 ($Al_2O_3 \approx 24$ % and $SiO_2 \approx 30$ %; Fe_2O_3 varying with compressive strength); Table 8.11 through Table 8.5 ($Al_2O_3 \approx 19$ % and $SiO_2 \approx 44$ %; Fe_2O_3 varying with compressive strength); Table 8.12 through Table 8.6 ($Al_2O_3 \approx 22$ % and $SiO_2 \approx 44$ %; Fe_2O_3 varying with compressive strength); and Table 8.13 through Table 8.7 ($Al_2O_3 \approx 15$ % and $SiO_2 \approx 37$ %; Fe_2O_3 varying with compressive strength).

A plot of Table 8.10 wherein $Al_2O_3 \approx 24$ % and $SiO_2 \approx 30$ % and Fe_2O_3 varying with compressive strength is shown in Figure 8.6. Similarly Figure 8.7 shows a plot of Fe_2O_3 with compressive strength wherein $Al_2O_3 \approx 19$ % and $SiO_2 \approx 44$ %; Fig. 8.8 shows a plot of Fe_2O_3 with compressive strength wherein $Al_2O_3 \approx 22$ % and $SiO_2 \approx 44$ % and Figure 8.9 shows a plot of Fe_2O_3 with compressive strength wherein $Al_2O_3 \approx 15$ % and $SiO_2 \approx 37$ %.

From Figure 8.6 to Figure 8.9, it is clearly observed that with increase in total percentage of Fe_2O_3 in a brick, its compressive strength decreases gradually. Hence, it is concluded that percentage of Fe_2O_3 present in a brick certainly has a negative impact on its compressive strength.

Table 8.10 Variation of Fe_2O_3 with compressive strength

($Al_2O_3 \approx 24$ % and $SiO_2 \approx 30$ %)

Total percentage of Fe_2O_3	Compressive strength (MPa)
21.89	11.02
22.78	10.45
22.05	10.06
22.93	9.36
23.97	8.08
24.70	6.70

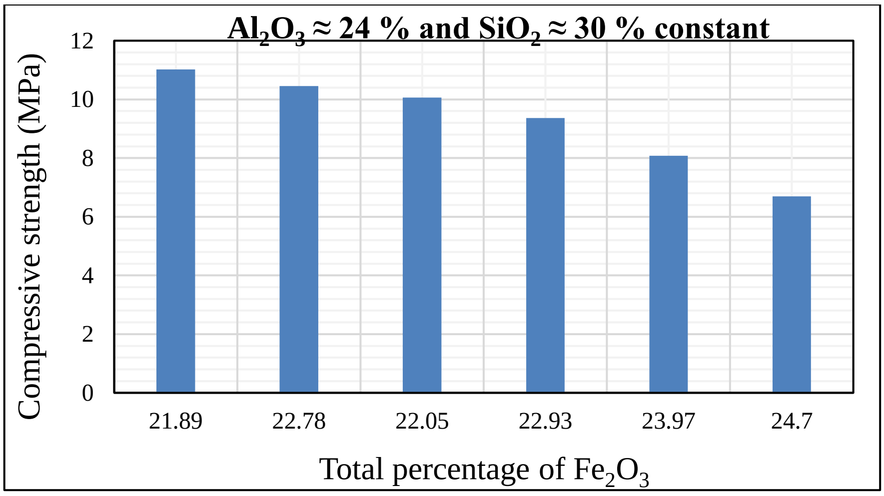


Fig. 8.6 Total percentage of Fe_2O_3 vs. compressive strength

Table 8.11 Variation of Fe_2O_3 with compressive strength (Al_2O_3 ≈ 19 % and SiO_2 ≈ 44 %)

Total percentage of Fe_2O_3	Compressive strength (MPa)
17.44	11.92
17.64	9.86
18.52	8.07
19.60	6.86
19.80	5.18

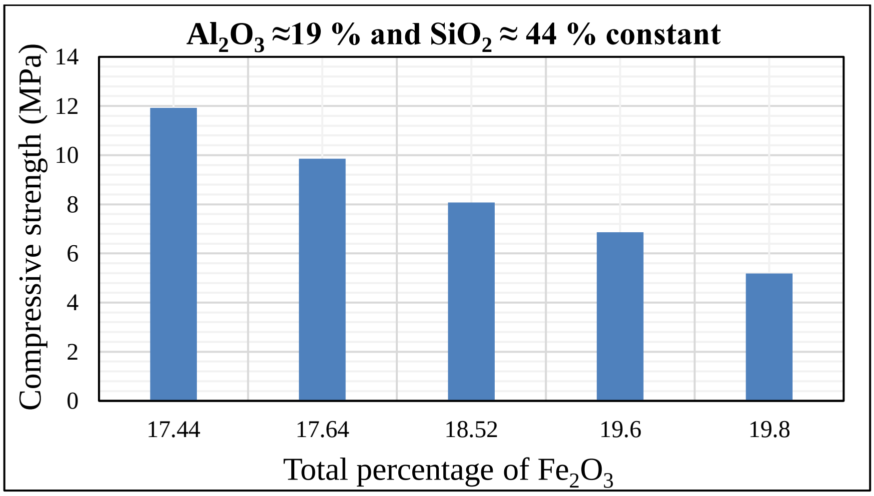


Fig. 8.7 Total percentage of Fe_2O_3 vs. compressive strength

Table 8.12 Variation of Fe_2O_3 with compressive strength (Al_2O_3 ≈ 22 % and SiO_2 ≈ 44 %)

Total percentage of Fe_2O_3	Compressive strength (MPa)
13.60	8.75
14.48	7.16
14.92	6.03
15.80	5.34

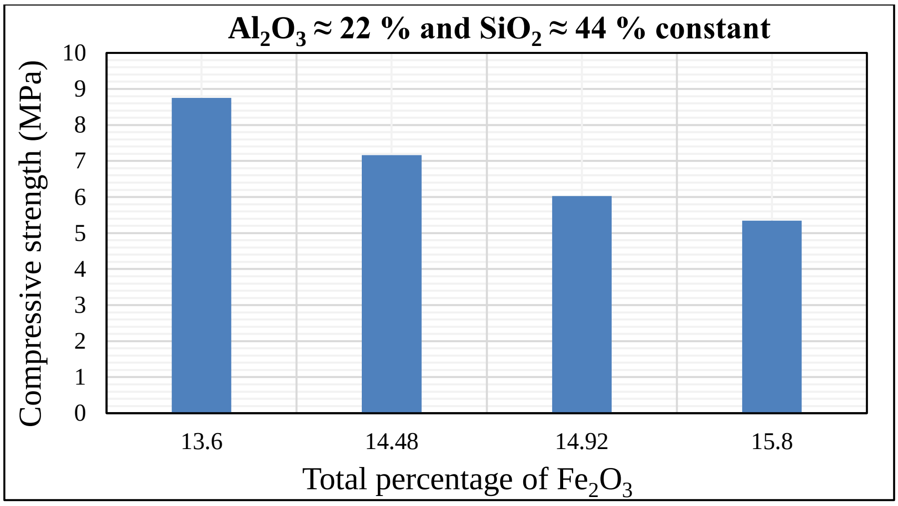


Fig. 8.8 Total percentage of Fe_2O_3 vs. compressive strength

Table 8.13 Variation of Fe_2O_3 with compressive strength ($Al_2O_3 \approx 15$ % and $SiO_2 \approx 37$ %)

Total percentage of Fe_2O_3	Compressive strength (MPa)
24.59	13.50
24.94	11.87
25.21	10.01
25.41	5.72
25.82	5.56

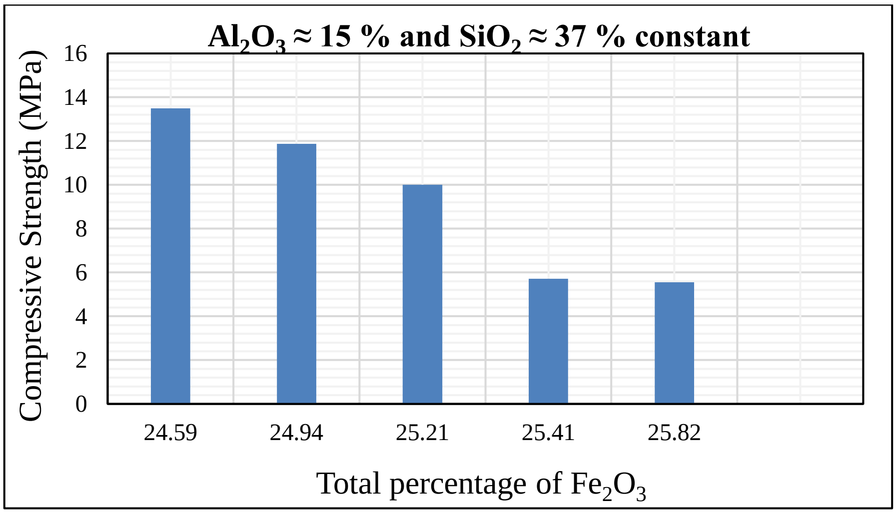


Fig. 8.9 Total percentage of Fe_2O_3 vs. compressive strength

8.4 CLOSURE

In this chapter, attempt was made to investigate the impact of chemical composition of bricks on its compressive strength. Based on the available data, investigation has revealed that there is no proper relationshp between the total percentages of SiO_2 and Al_2O_3 present in a brick with its compressive strength. With increase in total percentage of Fe_2O_3 present in a brick, its compressive strength was found to decrease gradually.

However, detailed work needs to be undertaken in future in this direction to confirm the above mentioned results. Due to limitations of extensive data on impact of chemical constituents in brick in the present investigation, it was not possible to carryout regression analysis in this research work.

CHAPTER – 9

9.0 CONCLUSIONS AND SCOPE FOR FUTURE WORK

9.1 CONCLUSIONS

Iron ore waste fines along with fly ash and cement were used in this research work for the purpose of making non-fired bricks. Iron ore waste fines with Fe_2O_3 below 30 % were only used in the process of brick making as fines with higher percentage of Fe_2O_3 may be used in future as ore by upgrading them. The following conclusions are drawn based on this research work;

1. Around 90 % of the collected iron ore waste fines was below 600 µ size. Hence, iron ore waste fines are directly suitable for preparation of non-fired bricks without going for any crushing, grinding or screening processes.
2. The investigation revealed that cement can be readily used as an additive/binding material for preparing non-fired bricks from iron ore waste fines found in iron ore mines. These bricks comply with IS Standards IS 13757:1993 of class designation 3.5, which can be used in the construction of simple temporary and cheap structures which are not exposed to heavy rains.
3. Bricks with 9 % cement content as an additive in brick making along with fly ash and iron ore waste fines will meet the desired compressive strength as per BIS guidelines of 35 kg cm^{-2} or 3.5 MPa with 28 days of curing period. With 10 % cement content in the brick with varying percentage of fly ash and iron ore waste fines, the bricks with several combinations attain the desired strength as per BIS standards much below 28 days (7 days, 14 days and 21 days) and therefore can be used as a construction material even without 28 days of curing the details of which are presented in this thesis.
4. All the bricks prepared with 9 % cement content as binding material and with curing of 7 days and above meet the BIS standards of water absorption (less than 20 % after 24 hours of immersion in water).
5. Investigation has revealed that bricks prepared with below 9 % cement as binding material will deform once removed from the mould and will have very low compressive strength of the order of 0.55 to 0.67 MPa which does not meet the required BIS specifications and hence non-fired bricks from iron ore waste fines should not be prepared containing cement as binding material of less than to 9 %.
6. Fly ash which is the waste from thermal power plants should also be used along with cement and iron ore waste in brick making process. The fine fly ash particles improves

the concrete pore structure thereby stimulating early strength development and also increases the compressive strength of bricks. Further addition of fly ash in the brick, makes the brick lighter. It is found that there is a significant reduction in weight of the bricks of around 0.5 kg by using fly ash compared to that of bricks prepared without fly ash. Hence, it is recommended to use fly ash in the process of brick making using cement and iron ore waste fines. Further, use of fly ash in making brick is environmental friendly too.

7. It was found that the bricks prepared with 30 % cement, 25 % cement, 20 % cement, 15 % cement and 10 % cement costs ₹ 10, ₹ 9.20, ₹ 8.70, ₹ 7.80 and ₹ 7.20 per brick (excluding profit), respectively, which is substantially below the cost of fired compressed bricks available in the market (costing ₹ 15 per brick). As the cost figures arrived in this research work are based on the cost computation of prepared bricks on laboratory scale, it is anticipated that the cost figures may reduce further when the brick preparation is done on industrial scale.
8. A number of regression equations have been developed for predicting compressive strength and percentage of water absorption of prepared bricks with different days of curing. These equations can be readily used to find out the compressive strength and water absorption of bricks with acceptable level of accuracy.
9. Based on the available data, results of investigation on the impact of chemical composition of bricks on its compressive strength revealed no appropriate relationship with total percentages of SiO_2 and Al_2O_3 present in a brick. However, with increase in total percentage of Fe_2O_3 present in a brick, its compressive strength was found to decrease gradually. Hence, it is suggested to prepare non fired bricks from iron ore waste fines containing low percentage of Fe_2O_3, which is also desirable from the point of view of mineral conservation.

9.2 SCOPE FOR FUTURE WORK

1. Detailed investigation can be taken up in future to study exclusively the influence of different types of chemical constituents which are present in a brick on its compressive strength and water absorption.
2. Further work may also be taken up in manufacturing of bricks using different types of materials as binding ingredients.

REFERENCES

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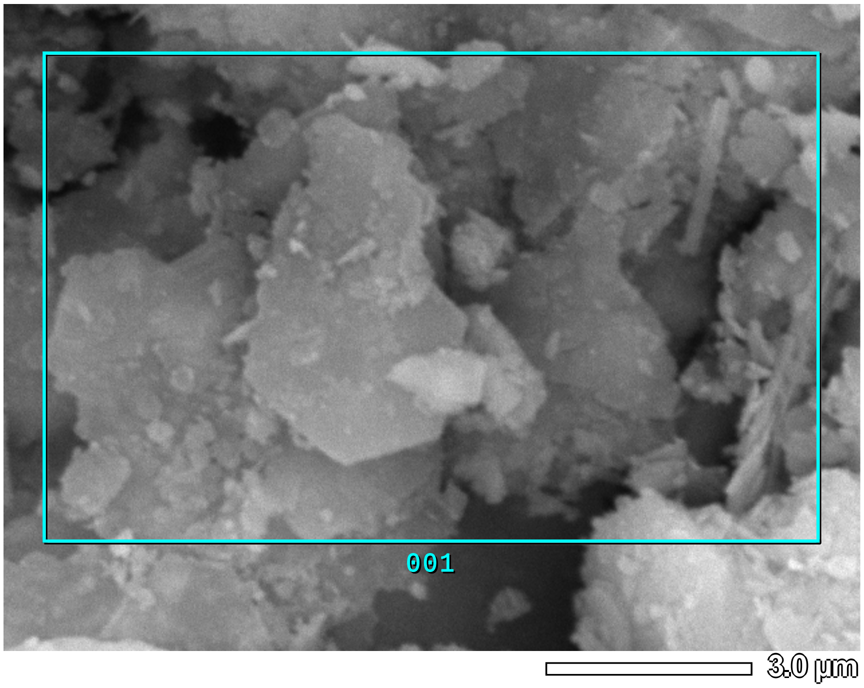
ANNEXURE - I



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Mag            : x 10,000
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Pixel          : 640 x 480
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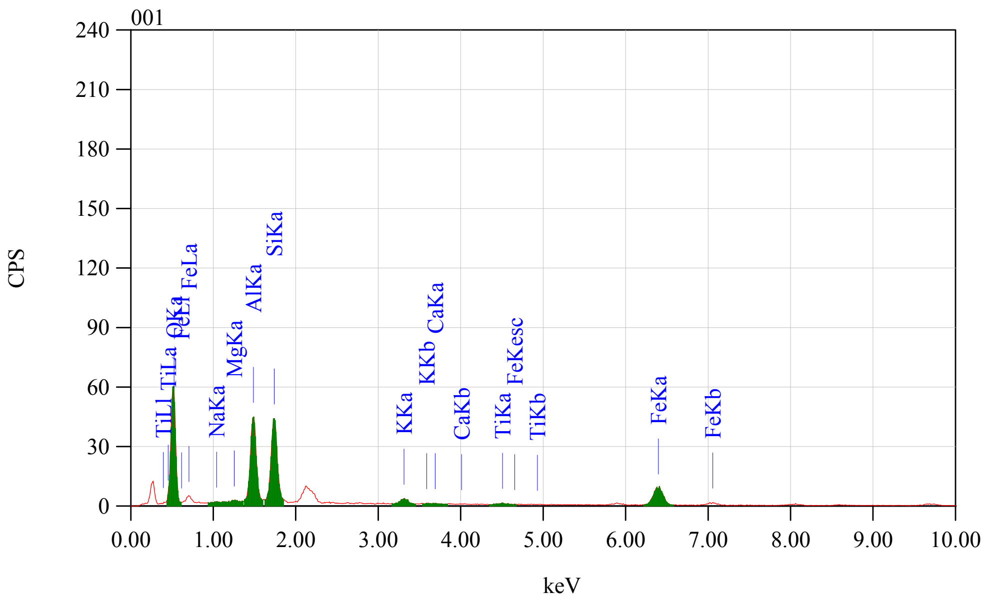

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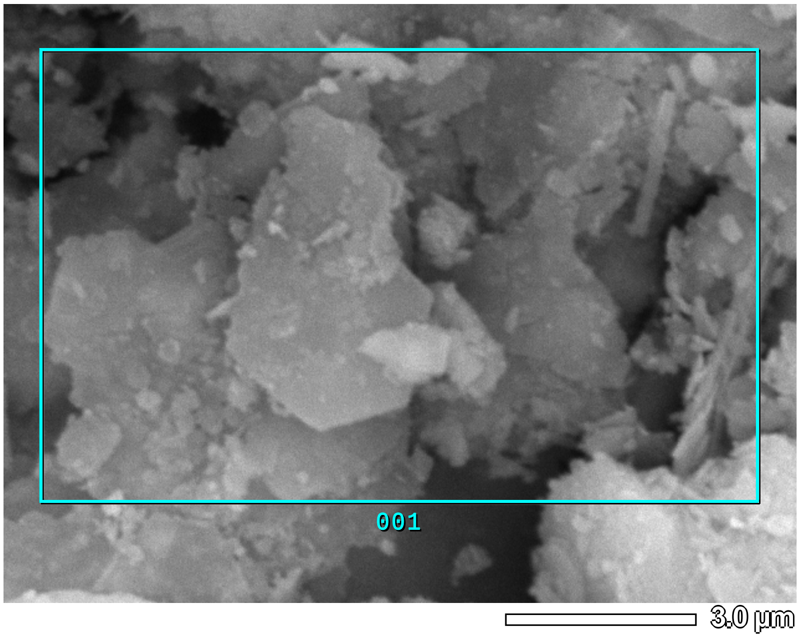
Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 68.27 sec
Live Time     : 50.00 sec
Dead Time     : 25 %
Counting Rate: 2817 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2581
Total Oxide : 24.0
Element         (keV)   mass%  Error%    Mol%  Compound   mass%  Cation       K
 O                      44.04
Na K            1.041    0.18    0.31    0.28  Na2O        0.24    0.07    0.2534
Mg K            1.253    0.45    0.29    1.34  MgO         0.74    0.16    0.5858
Al K            1.486   17.96    0.29   24.29  Al2O3      33.94    5.81   28.7506
Si K            1.739   19.83    0.39   51.53  SiO2       42.43    6.16   31.1501
 K K            3.312    1.50    0.22    1.40  K2O         1.81    0.34    3.5630

Ca K            3.690    0.19    0.30    0.34  CaO         0.26    0.04    0.4735
Ti K            4.508    0.49    0.43    0.75  TiO2        0.82    0.09    1.0828
Fe K            6.398   15.35    0.59   20.06  FeO        19.75    2.40   34.1407
Total                  100.00          100.00            100.00   15.05
```

Fig. 1 SEM Results for Sample-1



```
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Volt          : 20.00 kV
Mag           : x 10,000
Date          : 2013/12/11
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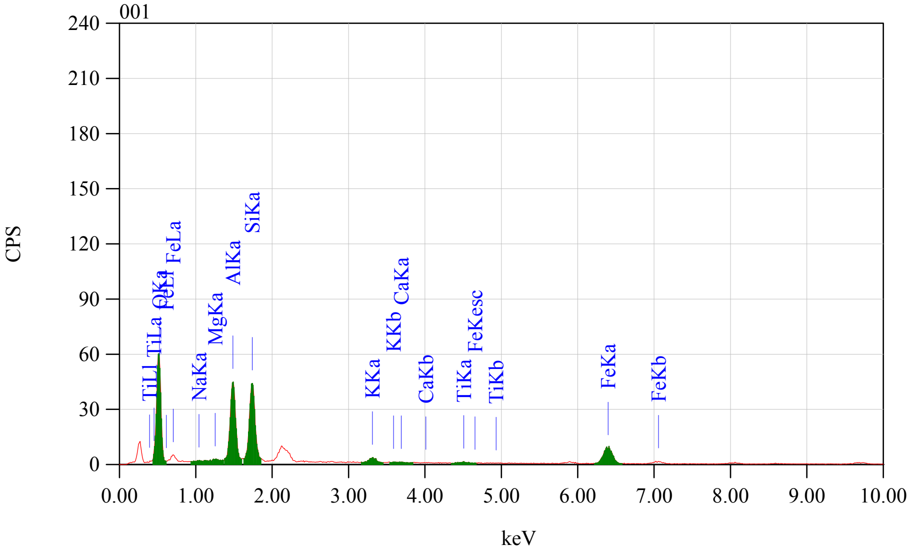
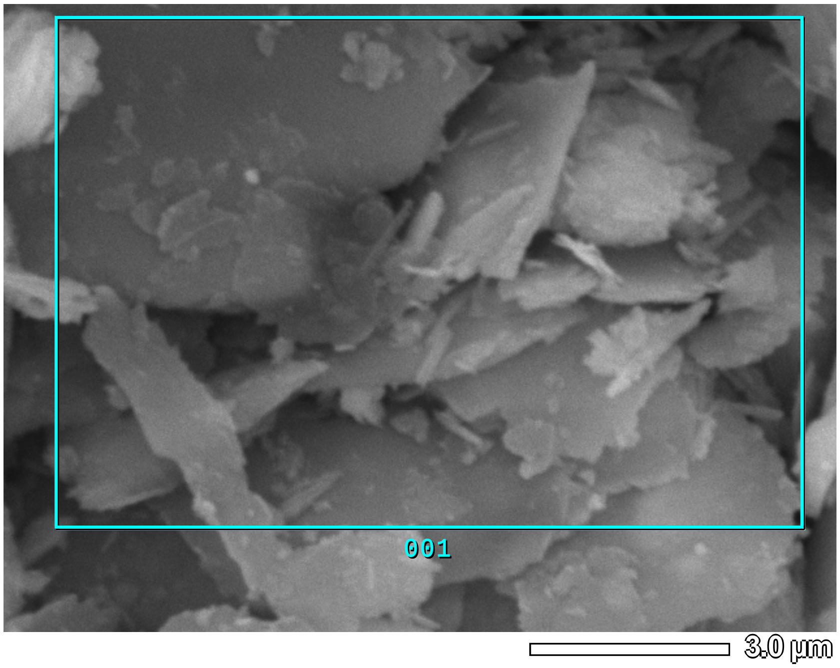


```
Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage  : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 68.27 sec
Live Time     : 50.00 sec
Dead Time     : 25 %
Counting Rate: 2817 cps
Energy Range  :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2581
Total Oxide : 24.0
Element        (keV)   mass%  Error%    Mol%  Compound    mass%  Cation       K
 O                     44.04
Na K           1.041    0.18    0.31    0.28  Na2O         0.24    0.07    0.2534
Mg K           1.253    0.45    0.29    1.34  MgO          0.74    0.16    0.5858
Al K           1.486   17.96    0.29   24.29  Al2O3       33.94    5.81   28.7506
Si K           1.739   19.83    0.39   51.53  SiO2        42.43    6.16   31.1501
 K K           3.312    1.50    0.22    1.40  K2O          1.81    0.34    3.5630
Ca K           3.690    0.19    0.30    0.34  CaO          0.26    0.04    0.4735
Ti K           4.508    0.49    0.43    0.75  TiO2         0.82    0.09    1.0828
Fe K           6.398   15.35    0.59   20.06  FeO         19.75    2.40   34.1407
Total                 100.00          100.00             100.00   15.05
```

Fig. 2 SEM Results for Sample-2



```
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Mag            : x 10,000
Date           : 2014/01/21
Pixel          : 640 x 480
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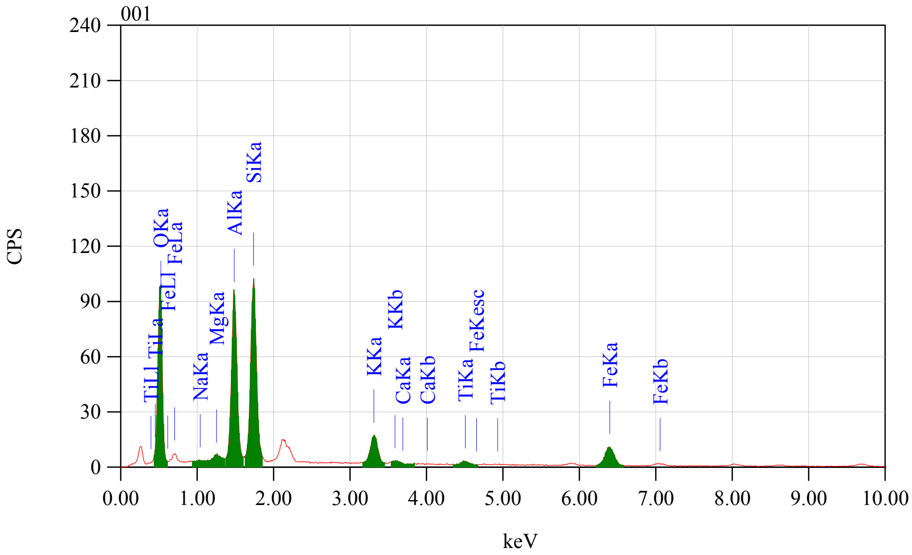
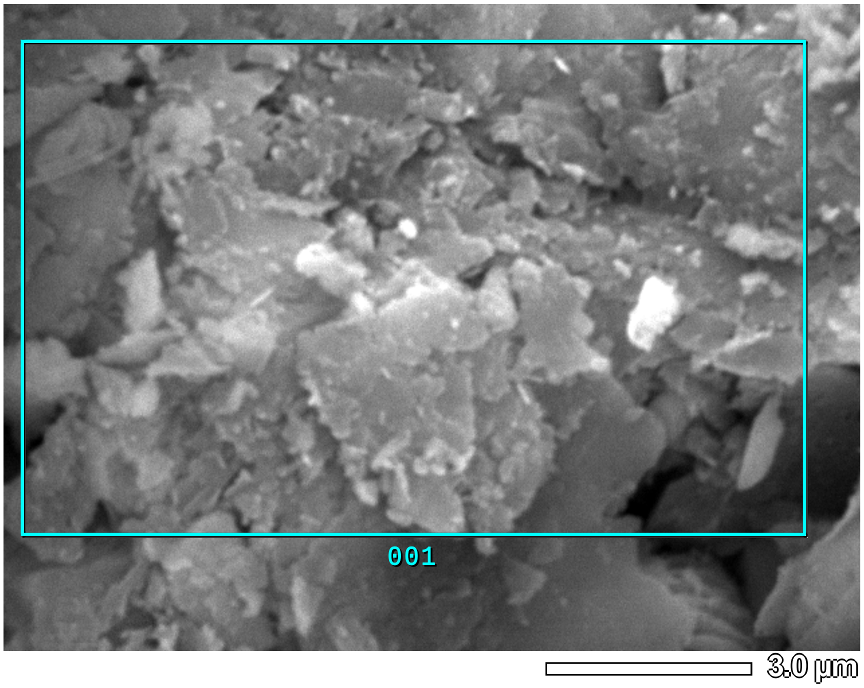


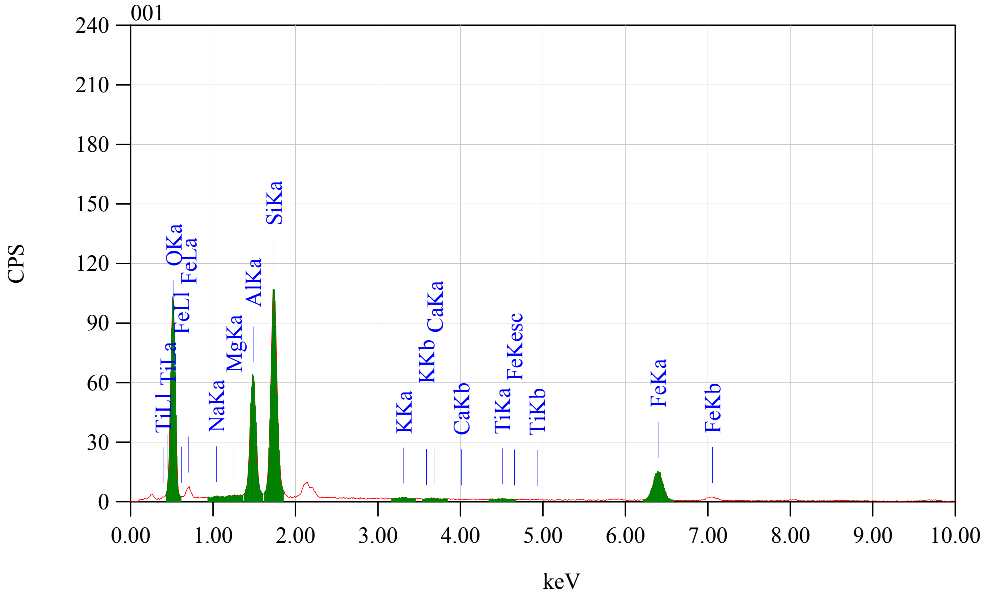
```
Acquisition Parameter
Instrument     : 6380(LA)
Acc. Voltage : 20.0 kV
Probe Current: 1.00000 nA
PHA mode       : T4
Real Time      : 89.83 sec
Live Time      : 50.00 sec
Dead Time      : 43 %
Counting Rate: 5515 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2023
Total Oxide : 24.0
Element         (keV)   mass%  Error%    Mol%  Compound    mass%  Cation        K
 O                      45.41
Na K            1.041    0.14    0.20    0.22  Na2O         0.19    0.05   0.2221
Mg K            1.253    0.54    0.19    1.62  MgO          0.90    0.19   0.7704
Al K            1.486   17.97    0.19   24.28  Al2O3       33.94    5.63  30.8577
Si K            1.739   22.00    0.26   57.11  SiO2        47.06    6.62  36.3007
 K K            3.312    4.38    0.16    4.08  K2O          5.27    0.95  10.4828
Ca K            3.690    0.02    0.21    0.03  CaO          0.03    0.00   0.0476
Ti K            4.508    0.86    0.30    1.31  TiO2         1.43    0.15   1.8810
Fe K            6.398    8.69    0.41   11.35  FeO         11.18    1.32  19.4377
Total                  100.00         100.00              100.00   14.91
```

Fig. 3 SEM Results for Sample-3



```
Title          : IMG2
---------------------------
Instrument     :
Volt           : 20.00 kV
Mag            : x 10,000
Date           : 2013/12/13
Pixel          : 640 x 480
```

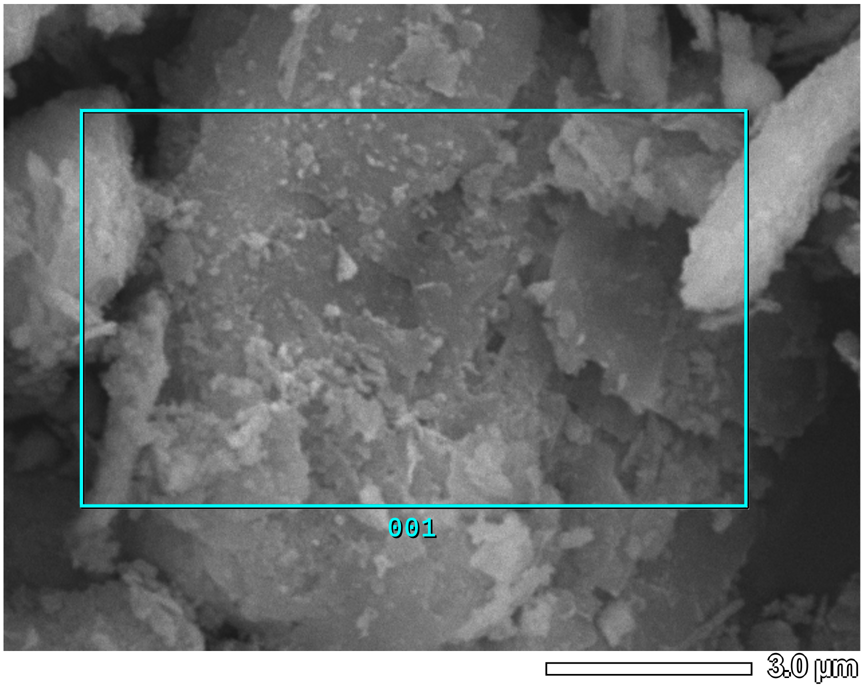


```
Acquisition Parameter
Instrument     : 6380(LA)
Acc. Voltage   : 20.0 kV
Probe Current: 1.00000 nA
PHA mode       : T4
Real Time      : 78.16 sec
Live Time      : 50.00 sec
Dead Time      : 34 %
Counting Rate: 4010 cps
Energy Range :  0 - 20 keV
```

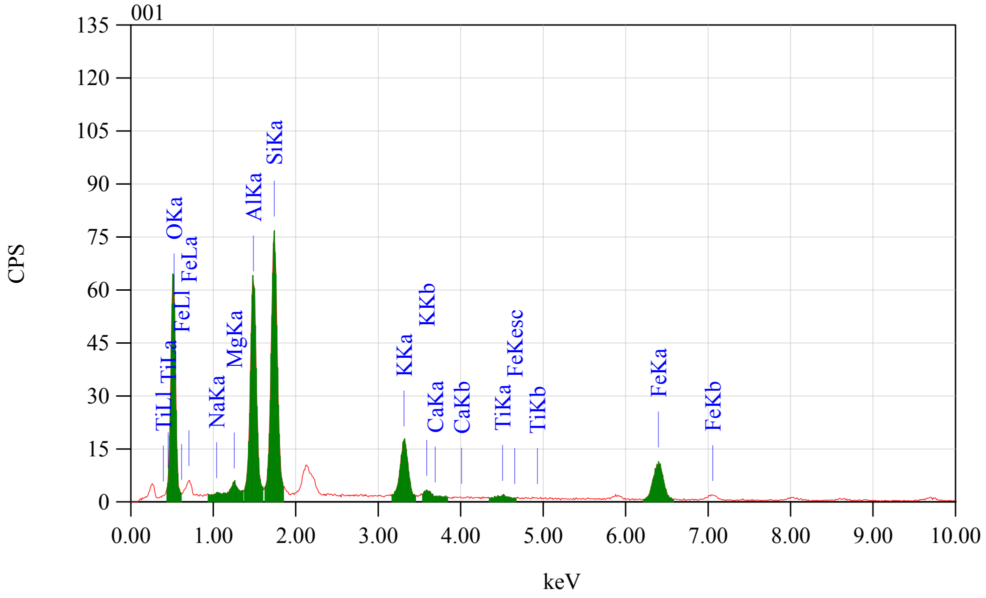
```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.1712
Total Oxide : 24.0
Element         (keV)    mass%  Error%     Mol%  Compound    mass%  Cation        K
 O                       45.91
Na K            1.041     0.23    0.18     0.34  Na2O         0.30    0.08    0.3351
Mg K            1.253     0.04    0.17     0.11  MgO          0.06    0.01    0.0507
Al K            1.486    13.95    0.17    18.03  Al2O3       26.35    4.32   23.3599
Si K            1.739    25.68    0.22    63.78  SiO2        54.94    7.65   43.8570
 K K            3.312     0.20    0.13     0.18  K2O          0.24    0.04    0.4759
Ca K            3.690     0.08    0.18     0.14  CaO          0.11    0.02    0.2096
Ti K            4.508     0.21    0.25     0.31  TiO2         0.35    0.04    0.4734
Fe K            6.398    13.71    0.35    17.13  FeO         17.64    2.05   31.2385
Total                   100.00           100.00             100.00   14.22
```

Fig. 4 SEM Results for Sample-4

JED-2300 *AnalysisStation* JEOL



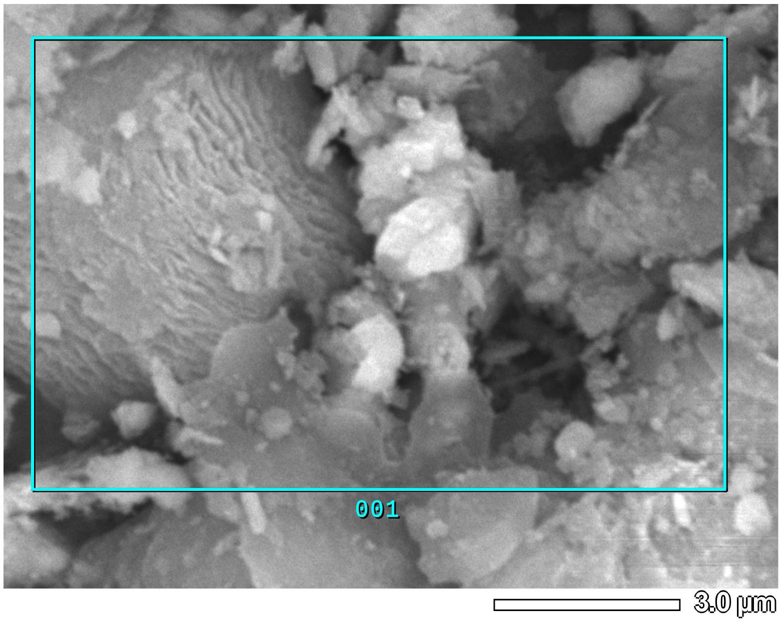
```
Title          : IMG2
---------------------------
Instrument     :
Volt           : 20.00 kV
Mag            : x 10,000
Date           : 2013/12/11
Pixel          : 640 x 480
```



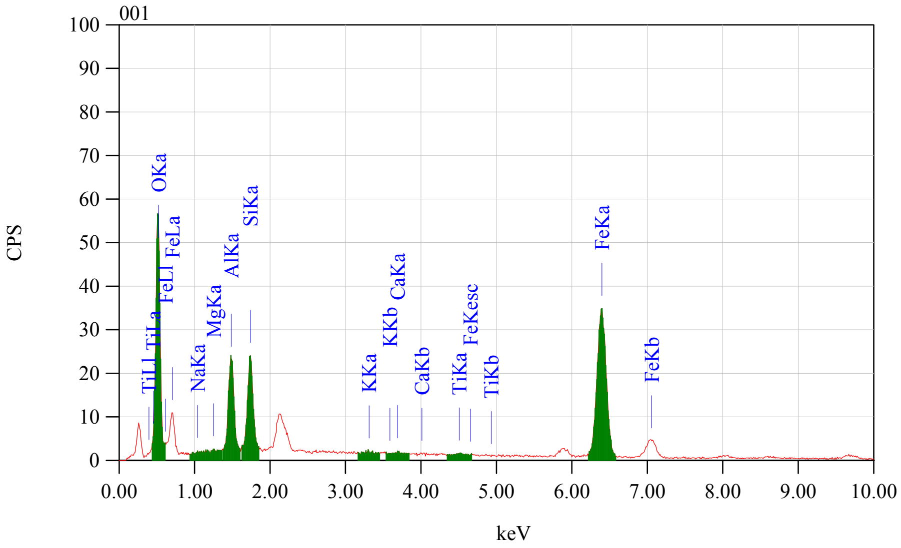
```
Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage  : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 75.89 sec
Live Time     : 50.00 sec
Dead Time     : 32 %
Counting Rate: 3803 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.1944
Total Oxide : 24.0
Element         (keV)    mass%  Error%    Mol%  Compound    mass%  Cation       K
 O                       43.91
Na K            1.041     0.17    0.17    0.27  Na2O         0.23    0.07    0.2495
Mg K            1.253     0.91    0.15    2.71  MgO          1.51    0.33    1.2067
Al K            1.486    16.22    0.16   21.75  Al2O3       30.65    5.26   25.9765
Si K            1.739    21.16    0.21   54.51  SiO2        45.26    6.59   33.6257
 K K            3.312     5.83    0.12    5.39  K2O          7.02    1.30   13.5147
Ca K
Ti K            4.508     0.40    0.24    0.60  TiO2         0.66    0.07    0.8389
Fe K            6.398    11.40    0.33   14.77  FeO         14.66    1.78   24.5880
Total                   100.00          100.00             100.00   15.40
```

Fig. 5 SEM Results for Sample-5



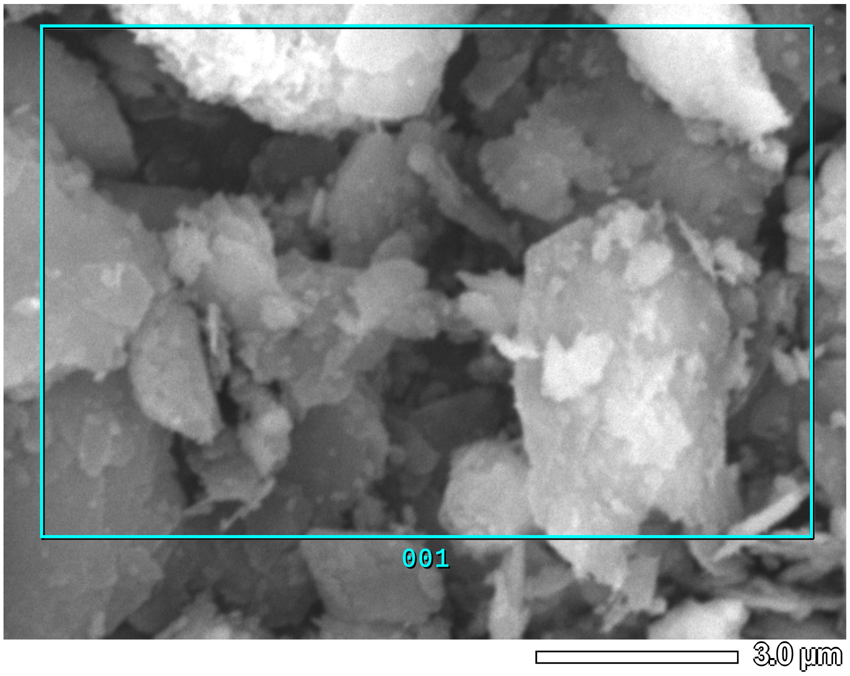
```
Title          : IMG2
---------------------------
Instrument     :
Volt           : 20.00 kV
Mag            : x 10,000
Date           : 2013/12/13
Pixel          : 640 x 480
```



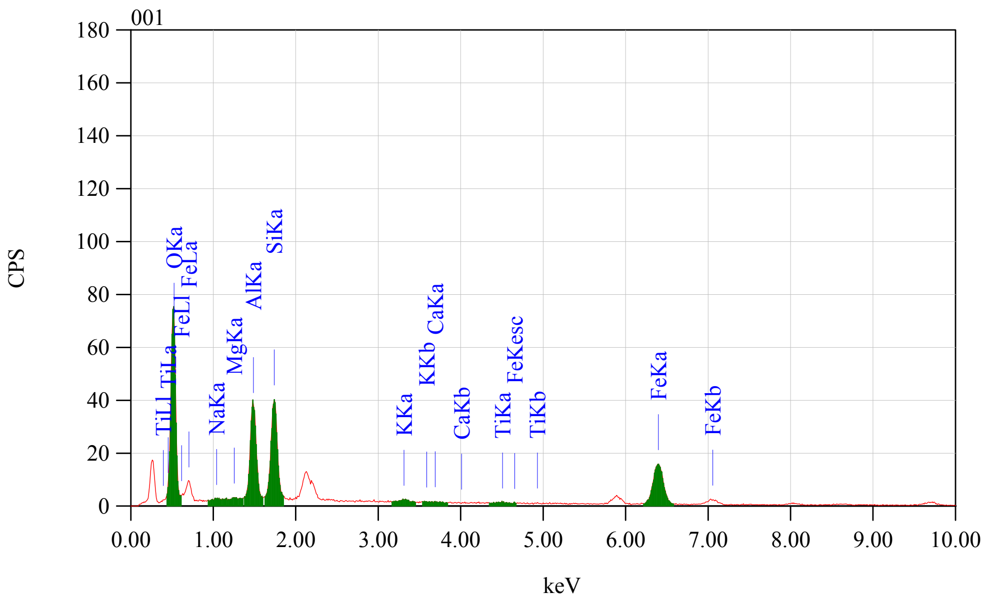
```
Acquisition Parameter
Instrument     : 6380(LA)
Acc. Voltage   : 20.0 kV
Probe Current: 1.00000 nA
PHA mode       : T4
Real Time      : 70.47 sec
Live Time      : 50.00 sec
Dead Time      : 28 %
Counting Rate: 3219 cps
Energy Range :   0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2599
Total Oxide : 24.0
Element         (keV)    mass%  Error%     Mol%  Compound    mass%  Cation       K
 O                       33.04
Na K            1.041     0.14    0.35     0.23  Na2O         0.19    0.07   0.1045
Mg K            1.253     0.16    0.31     0.47  MgO          0.26    0.08   0.1119
Al K            1.486     9.92    0.29    13.42  Al2O3       18.75    4.27   9.1599
Si K            1.739     9.00    0.32    23.38  SiO2        19.25    3.72   9.6732
 K K            3.312     0.17    0.17     0.16  K2O          0.21    0.05   0.3151
Ca K            3.690     0.24    0.22     0.44  CaO          0.34    0.07   0.4738
Ti K            4.508     0.31    0.31     0.47  TiO2         0.51    0.07   0.5303
Fe K            6.398    47.02    0.44    61.44  FeO         60.49    9.79  79.6314
Total                   100.00           100.00             100.00   18.13
```

Fig. 6 SEM Results for Sample-6



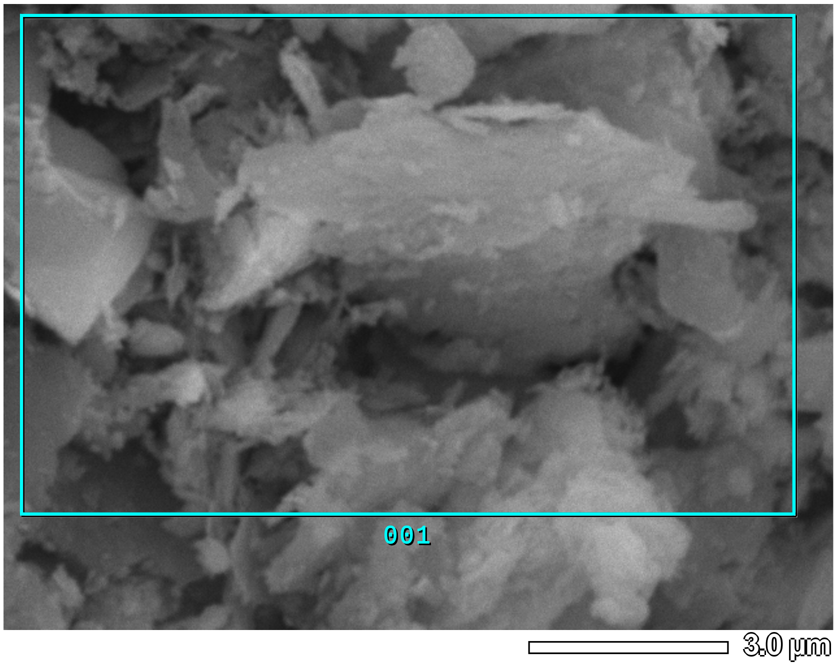
```
Title         : IMG2
---------------------------
Instrument    :
Volt          : 20.00 kV
Mag           : x 10,000
Date          : 2013/12/13
Pixel         : 640 x 480
```



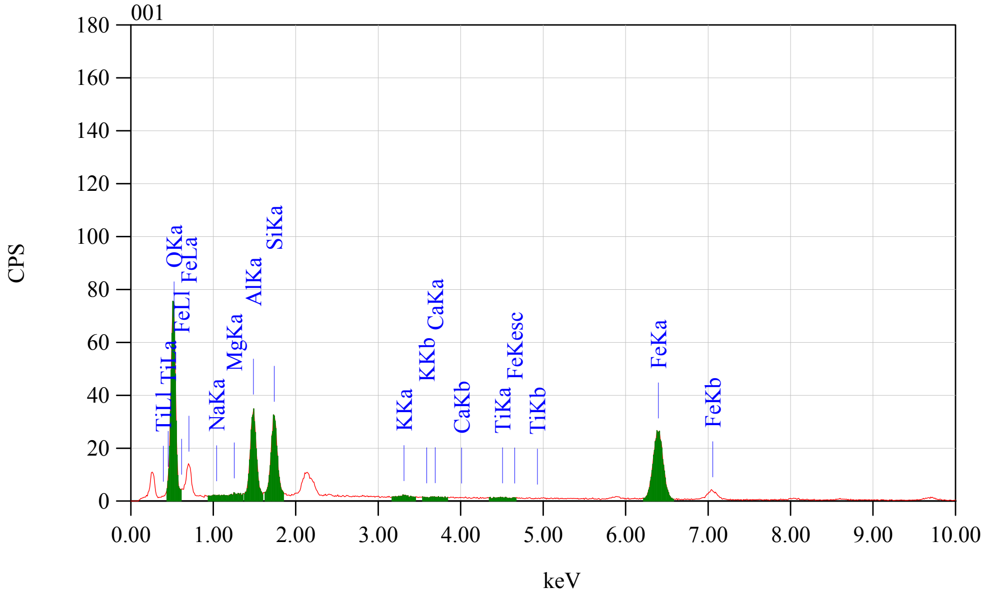
```
Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 72.34 sec
Live Time     : 50.00 sec
Dead Time     : 30 %
Counting Rate: 3528 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2858
Total Oxide : 24.0
Element         (keV)   mass%  Error%    Mol%  Compound   mass%  Cation       K
 O                      41.19
Na K            1.041    0.42    0.45    0.67  Na2O        0.57    0.17   0.5023
Mg K            1.253    0.34    0.41    1.02  MgO         0.56    0.13   0.3752
Al K            1.486   15.87    0.40   21.42  Al2O3      29.99    5.48  21.9550
Si K            1.739   17.06    0.50   44.22  SiO2       36.49    5.66  24.3953
 K K            3.312    0.47    0.28    0.44  K2O         0.57    0.11   1.0507
Ca K            3.690    0.05    0.37    0.09  CaO         0.07    0.01   0.1199
Ti K            4.508    0.28    0.53    0.42  TiO2        0.47    0.05   0.5849
Fe K            6.398   24.32    0.74   31.72  FeO        31.29    4.06  51.0166
Total                  100.00          100.00            100.00   15.68
```

Fig. 7 SEM Results for Sample-7



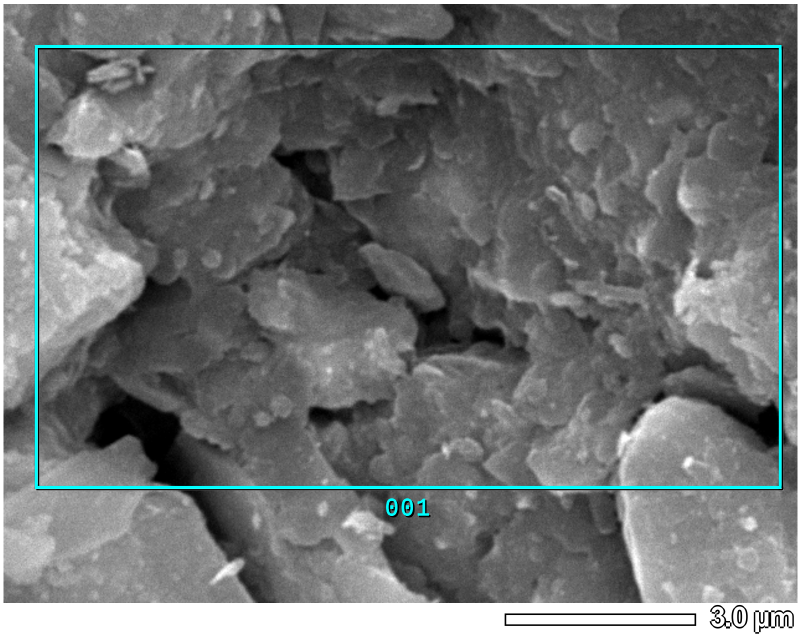
```
Title         : IMG2
---------------------------
Instrument    :
Volt          : 20.00 kV
Mag           : x 10,000
Date          : 2013/12/13
Pixel         : 640 x 480
```



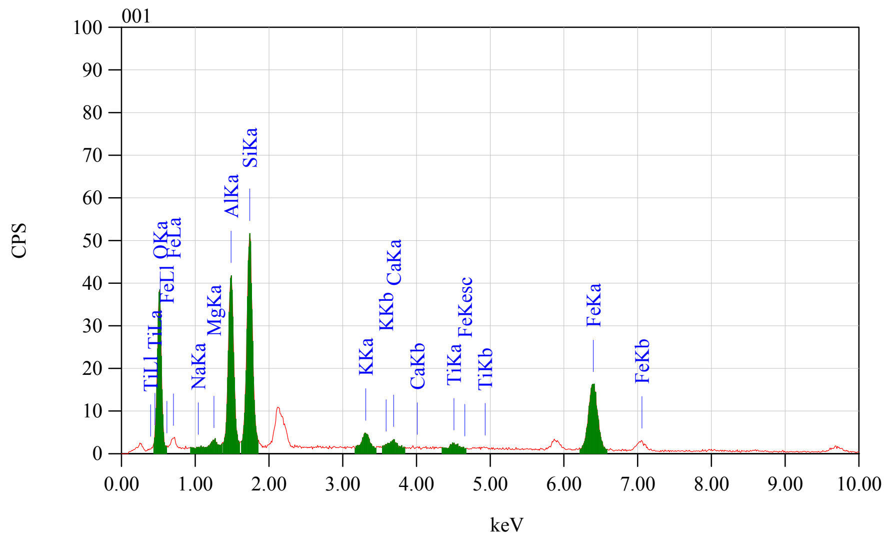
```
Acquisition Parameter
Instrument    : 6380(LA)
Acc. Voltage  : 20.0 kV
Probe Current: 1.00000 nA
PHA mode      : T4
Real Time     : 71.21 sec
Live Time     : 50.00 sec
Dead Time     : 29 %
Counting Rate: 3338 cps
Energy Range  :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2482
Total Oxide : 24.0
Element         (keV)    mass%   Error%     Mol%  Compound    mass%   Cation        K
 O                       36.75
Na K            1.041     0.05     0.36     0.09  Na2O         0.07     0.02    0.0488
Mg K            1.253     0.25     0.32     0.75  MgO          0.41     0.11    0.2167
Al K            1.486    13.18     0.30    17.88  Al2O3       24.90     5.10   14.6095
Si K            1.739    12.36     0.36    32.23  SiO2        26.45     4.60   15.0776
 K K            3.312     0.30     0.19     0.28  K2O          0.36     0.08    0.6003
Ca K            3.690     0.17     0.25     0.30  CaO          0.23     0.04    0.3563
Ti K            4.508     0.15     0.36     0.22  TiO2         0.24     0.03    0.2740
Fe K            6.398    36.79     0.50    48.24  FeO         47.33     6.88   68.8169
Total                   100.00            100.00             100.00    16.87
```

Fig. 8 SEM Results for Sample-8



```
Title          : IMG2
---------------------------
Instrument     :
Volt           : 20.00 kV
Mag            : x 10,000
Date           : 2014/01/21
Pixel          : 640 x 480
```



```
Acquisition Parameter
Instrument     : 6380(LA)
Acc. Voltage   : 20.0 kV
Probe Current: 1.00000 nA
PHA mode       : T4
Real Time      : 70.86 sec
Live Time      : 50.00 sec
Dead Time      : 30 %
Counting Rate: 3547 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.2466
Total Oxide : 24.0
Element         (keV)   mass%   Error%   Mol%  Compound    mass%  Cation       K
 O                      41.73
Na K            1.041    0.05    0.20    0.08  Na2O         0.06    0.02   0.0585
Mg K            1.253    0.66    0.19    1.95  MgO          1.10    0.25   0.7521
Al K            1.486   14.53    0.18   19.30  Al2O3       27.45    4.95  20.4320
Si K            1.739   18.49    0.23   47.19  SiO2        39.55    6.06  27.1250
 K K            3.312    1.59    0.13    1.46  K2O          1.91    0.37   3.5512
Ca K            3.690    0.74    0.17    1.33  CaO          1.04    0.17   1.7715
Ti K            4.508    0.82    0.25    1.23  TiO2         1.37    0.16   1.6957
Fe K            6.398   21.39    0.35   27.46  FeO         27.52    3.52  44.6139
Total                  100.00          100.00             100.00   15.51
```

Fig. 9 SEM Results for Sample-9

ANNEXURE - II

Table 1 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

	Cement (C) : Fly ash (FA) : Iron ore waste(IOW)															
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	6.90	7.50	8.90	12.00	5.86	6.50	7.85	11.20	4.60	5.60	6.90	10.90	4.00	5.40	6.50	10.50
S2	6.57	7.00	8.45	11.46	5.47	6.53	7.90	11.25	4.65	5.40	6.59	10.79	4.10	5.49	6.45	10.65
S3	7.00	7.45	8.60	11.53	5.75	6.44	8.00	11.10	4.81	5.36	6.60	10.75	4.70	5.60	6.40	10.45
S4	6.89	6.98	8.00	11.60	5.60	6.87	8.25	11.15	5.00	5.42	6.75	10.76	4.55	5.25	6.46	10.55
S5	6.94	7.24	8.85	11.85	5.65	6.90	8.50	11.30	4.79	5.45	6.80	10.85	4.60	5.45	6.49	10.60
Average compressive strength (MPa)	6.86	7.23	8.56	11.69	5.67	6.65	8.10	11.20	4.77	5.45	6.73	10.81	4.39	5.44	6.46	10.55

Contd….

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	10:25:65 (C:FA:IOW) (E)				05:30:65 (C:FA:IOW) (F)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	2.30	3.40	4.10	4.50	0.56	0.59	0.62	0.65
S2	2.28	3.20	4.20	4.44	0.58	0.65	0.63	0.70
S3	2.38	3.50	4.25	4.46	0.55	0.60	0.62	0.68
S4	2.36	3.46	4.00	4.48	0.54	0.58	0.60	0.64
S5	2.29	3.30	4.15	4.40	0.56	0.63	0.60	0.65
Average compressive strength (MPa)	2.32	3.37	4.14	4.46	0.56	0.61	0.61	0.66

Table 2 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	8.58	8.82	11.30	11.52	5.87	7.55	7.54	8.67	4.33	5.37	6.38	6.96	3.39	4.14	4.53	4.37	2.90	2.95	3.50	3.79
S2	7.50	8.71	11.25	11.43	5.95	7.38	7.72	8.65	4.74	5.45	6.92	6.85	3.08	4.06	4.27	4.58	2.63	2.84	3.53	3.85
S3	7.97	8.77	11.14	11.75	5.71	7.29	7.61	8.74	4.63	5.25	6.67	7.12	3.21	4.21	4.40	4.44	2.79	2.80	3.60	3.80
S4	7.60	8.75	11.20	11.58	5.80	7.45	7.59	8.70	4.70	5.36	6.70	6.90	3.17	4.18	4.35	4.50	2.75	2.85	3.75	3.88
S5	7.75	8.80	11.28	11.65	5.78	7.50	7.65	8.69	4.55	5.40	6.75	6.88	3.10	4.15	4.40	4.48	2.65	2.84	3.65	3.90
Average compressive strength (MPa)	7.88	8.77	11.23	11.59	5.82	7.43	7.62	8.69	4.59	5.37	6.68	6.94	3.19	4.15	4.39	4.47	2.74	2.86	3.61	3.84

Table 3 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	11.57	11.56	11.77	11.97	8.66	8.72	8.98	9.38	7.51	8.04	8.11	8.39	2.71	2.97	3.96	4.61
S2	11.70	11.67	11.85	11.88	8.67	8.86	8.96	9.51	7.42	7.91	8.25	8.46	2.63	2.88	3.68	4.30
S3	11.67	11.77	11.84	12.01	8.52	8.78	8.91	9.56	7.31	8.07	8.10	8.32	2.68	2.90	3.72	4.45
S4	11.63	11.68	11.82	11.92	8.58	8.80	8.94	9.40	7.38	8.00	8.18	8.40	2.65	2.96	3.78	4.50
S5	11.60	11.70	11.79	11.98	8.60	8.76	8.95	9.52	7.44	8.45	8.16	8.35	2.70	2.92	3.84	4.39
Average compressive strength (MPa)	11.63	11.68	11.81	11.95	8.61	8.78	8.95	9.47	7.41	8.09	8.16	8.38	2.67	2.93	3.80	4.45

Table 4 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	4.45	4.84	5.05	5.85	3.05	4.33	4.45	5.57	2.47	2.99	3.31	3.62
S2	4.54	4.67	5.14	5.89	2.97	4.29	4.61	5.50	2.49	3.05	3.22	3.65
S3	4.48	4.75	5.12	5.86	3.00	4.30	4.50	5.48	2.57	3.12	3.28	3.69
S4	4.50	4.78	5.09	5.60	3.20	4.27	4.58	5.52	2.54	2.96	3.25	3.67
S5	4.46	4.82	5.10	5.75	3.15	4.32	4.44	5.40	2.50	3.10	3.30	3.64
Average compressive strength (MPa)	4.49	4.77	5.10	5.79	3.07	4.30	4.52	5.49	2.51	3.04	3.27	3.65

Table 5 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	2.40	2.47	3.44	5.36	1.85	2.64	2.72	3.53
S2	2.44	2.54	3.50	5.24	1.87	2.69	2.71	3.46
S3	2.49	2.49	3.46	5.28	1.84	2.65	2.74	3.58
S4	2.50	2.5	3.35	5.30	1.82	2.70	2.76	3.50
S5	2.46	2.52	3.49	5.40	1.80	2.66	2.70	3.55
Average compressive strength (MPa)	2.46	2.50	3.45	5.32	1.84	2.67	2.73	3.53

Table 6 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	1.59	1.65	2.87	3.58
S2	1.49	1.54	2.85	3.60
S3	1.40	1.56	2.84	3.64
S4	1.52	1.60	2.76	3.66
S5	1.46	1.66	2.70	3.69
Average compressive strength (MPa)	1.49	1.60	2.80	3.63

Table 7 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	4.95	5.96	9.72	10.94	4.78	5.17	9.40	9.79	4.30	4.74	9.03	10.52	3.59	4.73	7.9	8.07	2.21	3.30	5.24	5.35
S2	4.98	5.99	9.98	11.13	4.65	5.20	9.32	11.20	4.49	4.88	8.61	10.13	3.67	4.77	8.03	8.11	2.36	3.31	4.95	5.45
S3	4.51	6.07	11.17	10.98	4.64	5.25	9.34	9.88	4.41	4.79	8.67	10.15	3.62	4.82	7.95	8.14	2.29	3.35	4.99	5.37
S4	5.36	6.03	10.96	11.11	4.67	5.55	9.37	11.10	4.35	4.87	8.71	10.25	3.65	4.80	8.00	8.16	2.34	3.33	5.14	5.40
S5	5.25	6.08	11.00	11.09	4.70	5.56	9.31	9.92	4.45	4.80	9.20	10.35	3.60	4.81	7.98	8.15	2.31	3.40	5.20	5.44
Average compressive strength (MPa)	5.01	6.03	10.57	11.05	4.69	5.35	9.35	10.38	4.40	4.82	8.84	10.28	3.63	4.79	7.97	8.22	2.30	3.34	5.10	5.40

Table 8 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	5.51	7.20	11.73	12.28	5.02	5.84	10.37	10.94	3.91	4.94	8.61	10.51	2.74	4.08	6.15	7.78	2.61	3.85	6.59	6.75
S2	5.32	7.26	11.75	12.33	4.71	5.09	9.99	10.97	3.98	4.97	8.43	10.45	2.95	4.10	6.43	7.90	2.41	3.77	6.13	6.70
S3	5.39	7.29	11.77	12.30	4.77	5.25	10.01	11.00	4.02	5.01	8.55	10.39	2.77	4.45	6.20	7.96	2.47	3.79	6.19	6.66
S4	5.43	7.31	11.81	12.35	4.84	5.36	10.07	11.07	4.05	5.05	8.50	10.36	2.81	4.36	6.29	8.04	2.53	3.82	6.29	6.69
S5	5.50	7.35	11.79	12.31	5.05	5.72	10.00	11.11	3.99	5.09	8.57	10.55	2.91	4.70	6.35	8.01	2.57	3.80	6.47	6.72
Average compressive strength (MPa)	5.43	7.29	11.77	12.31	4.88	5.45	10.09	11.02	3.99	5.01	8.53	10.45	2.84	4.34	6.28	7.94	2.52	3.81	6.33	6.70

Table 9 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	4.27	6.93	9.98	10.38	3.75	6.12	9.04	9.30	3.53	6.47	6.78	7.84	2.39	5.51	6.19	6.61
S2	4.13	6.75	9.70	10.30	3.62	6.19	9.09	9.39	3.49	6.50	7.10	7.89	2.26	5.56	6.25	6.67
S3	4.17	6.80	9.76	10.35	3.68	6.20	9.11	9.35	3.51	6.56	7.35	7.93	2.29	5.60	6.34	6.70
S4	4.21	6.79	9.74	9.30	3.72	6.26	9.16	9.37	3.56	6.54	7.64	8.00	2.34	5.59	6.40	6.77
S5	4.24	6.89	9.90	9.96	3.77	6.24	9.18	9.40	3.50	6.49	7.59	7.94	2.31	5.55	6.55	6.75
Average compressive strength (MPa)	4.20	6.83	9.82	10.06	3.71	6.20	9.12	9.36	3.52	6.51	7.29	7.92	2.32	5.56	6.35	6.70

Table 10 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	4.52	8.04	8.45	8.94	4.07	7.70	7.96	8.03	2.40	4.55	4.89	5.40
S2	4.46	8.19	8.84	8.98	4.14	7.37	7.98	8.09	2.20	4.32	4.80	5.29
S3	4.44	8.20	8.49	8.96	4.10	7.44	7.90	8.11	2.35	4.36	4.79	5.39
S4	4.90	8.07	8.56	8.99	4.09	7.49	7.92	8.13	2.19	4.44	4.90	5.35
S5	4.50	8.11	8.66	8.92	4.16	7.55	8.01	8.05	2.39	4.50	4.80	5.42
Average compressive strength (MPa)	4.56	8.12	8.60	8.96	4.11	7.51	7.95	8.08	2.31	4.44	4.84	5.37

Table 11 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	2.85	5.49	5.64	6.59	2.09	4.68	5.36	5.54
S2	2.76	5.37	5.75	6.48	2.16	4.72	5.26	5.39
S3	2.79	5.39	5.67	6.51	2.11	4.70	5.29	5.42
S4	2.83	5.44	5.71	6.55	2.19	4.77	5.31	5.46
S5	2.86	5.50	5.77	6.6	2.20	4.69	5.38	5.50
Average compressive strength (MPa)	2.82	5.44	5.71	6.55	2.15	4.71	5.32	5.46

Table 12 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	1.42	4.21	4.04	4.14
S2	1.44	3.71	4.12	4.13
S3	1.49	3.74	4.09	4.17
S4	1.46	3.79	4.15	4.15
S5	1.50	4.12	4.11	4.16
Average compressive strength (MPa)	1.46	3.91	4.10	4.15

Table 13 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

	Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																			
Proportio of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	9.52	11.73	13.41	16.61	9.03	11.14	12.53	15.64	6.77	8.62	9.57	11.09	4.76	6.18	7.37	7.59	3.55	3.57	4.25	4.97
S2	9.78	11.70	13.27	16.38	9.06	11.23	12.81	15.41	6.62	8.23	9.36	11.14	4.62	6.13	7.45	7.62	3.57	3.58	4.29	4.83
S3	9.71	11.74	13.35	16.40	9.08	11.34	12.65	15.49	6.69	8.30	9.43	11.10	4.67	5.99	7.50	7.69	3.54	3.58	4.30	4.88
S4	9.76	11.71	13.39	16.55	9.10	11.30	12.67	15.55	6.66	8.36	9.52	11.15	4.69	6.10	7.39	7.00	3.53	3.56	4.28	4.94
S5	9.62	11.73	13.40	16.51	9.12	11.26	12.72	15.50	6.76	8.45	9.55	11.11	4.72	6.16	7.48	8.04	3.52	3.57	4.31	4.96
Average compressive strength (MPa)	9.68	11.72	13.36	16.49	9.08	11.25	12.68	15.52	6.70	8.39	8.49	11.12	4.69	6.11	7.44	7.59	3.54	3.57	4.29	4.92

Table 14 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	10.23	10.81	12.34	14.85	7.18	8.99	11.55	12.35	6.59	8.77	10.20	11.60	5.25	7.77	8.63	10.27	2.80	3.81	4.28	4.92
S2	10.06	10.51	12.41	14.22	7.23	9.46	11.59	12.90	6.36	8.54	10.94	11.29	5.29	7.38	8.88	10.01	2.78	3.49	4.23	4.98
S3	10.09	10.59	12.38	14.35	7.35	9.41	11.63	12.86	6.45	8.60	10.98	11.35	5.34	7.44	8.69	10.15	2.69	3.55	4.20	4.90
S4	10.15	10.65	12.36	14.29	7.45	9.00	11.60	12.40	6.50	8.73	11.12	11.30	5.38	7.56	8.75	10.10	2.77	3.59	4.25	4.93
S5	10.21	10.69	12.40	14.36	7.44	9.35	11.62	12.45	6.55	8.77	11.16	11.44	5.35	7.60	8.84	10.24	2.78	3.62	4.29	4.99
Average compressive strength (MPa)	10.15	10.65	12.38	14.41	7.33	9.24	11.60	12.59	6.49	8.68	10.88	11.40	5.32	7.55	8.76	10.75	2.76	3.61	4.25	4.94

Table 15 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

	Cement (C) : Fly ash (FA) : Iron ore waste(IOW)															
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	6.11	6.56	6.32	9.28	5.15	6.08	7.93	8.61	4.39	4.81	6.09	5.46	3.08	3.61	5.81	6.09
S2	5.92	6.30	8.10	9.31	5.06	6.15	7.64	8.22	4.36	4.53	6.38	6.77	2.93	3.83	5.85	6.10
S3	5.97	6.35	8.00	9.29	5.09	6.26	7.69	8.31	4.24	4.62	6.17	6.56	2.99	3.65	5.87	6.15
S4	6.10	6.43	7.99	9.30	5.11	6.24	7.71	8.45	4.29	4.59	6.35	6.67	3.05	3.78	5.95	6.17
S5	5.98	6.49	8.07	9.28	5.14	6.20	7.77	8.40	4.35	4.70	6.30	6.70	3.02	3.70	6.01	6.15
Average compressive strength (MPa)	6.02	6.43	7.70	9.29	5.11	6.19	7.75	8.40	4.33	4.65	6.26	6.43	3.01	3,71	5.90	6.13

Table 16 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	5.52	6.27	7.33	7.62	4.07	5.31	6.33	6.76	2.59	3.80	4.87	5.09
S2	5.59	6.34	7.45	7.71	4.09	5.39	6.39	6.76	2.62	3.67	4.69	5.26
S3	5.60	6.43	7.58	7.84	4.15	5,46	6.41	6.79	2.64	3.69	4.73	5.15
S4	5.57	6.41	7.55	7.77	4.18	5.57	6.58	7.03	2.60	3.75	4.78	5.18
S5	5.53	6.39	7.57	7.83	4.18	5.56	6.49	7.08	2.64	3.87	4.84	5.24
Average compressive strength (MPa)	5.56	6.37	7.50	7.75	4.13	5.46	6.44	6.89	2.62	3.76	4.78	5.18

Table 17 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	4.95	5.23	5.49	5.76	4.23	4.50	4.69	5.02
S2	4.76	5.29	5.34	5.97	4.27	4.57	4.71	5.01
S3	4.83	5.25	5.37	5.85	4.34	4.53	4.68	5.09
S4	4.89	5.31	5.44	5.89	4.45	4.58	4.70	5.06
S5	4.94	5.30	5.43	5.90	4.46	4.55	4.69	5.10
Average compressive strength (MPa)	4.87	5.28	5.41	5.87	4.35	4.55	4.69	5.06

Table 18 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	3.31	3.39	4.04	4.20
S2	3.34	3.34	3.78	4.12
S3	3.36	3.43	3.81	4.16
S4	3.38	3.38	3.87	4.19
S5	3.35	3.44	4.00	4.13
Average compressive strength (MPa)	3.35	3.40	3.90	4.16

Table 19 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	6.03	6.32	7.98	17.08	4.42	7.38	7.70	10.58	4.14	5.97	6.51	9.88	3.96	5.33	5.61	8.76	2.22	2.72	3.29	5.30
S2	5.89	6.18	7.96	17.16	4.26	7.36	7.49	10.50	4.21	5.80	6.30	9.96	4.02	5.30	5.50	8.79	2.37	2.76	3.30	5.25
S3	5.90	6.21	8.04	17.10	4.30	7.29	7.55	10.54	4.17	5.95	6.38	9.90	3.98	5.13	5.45	8.85	2.30	2.82	3.28	5.10
S4	5.95	6.26	8.00	17.00	4.38	7.28	7.60	10.56	4.16	5.82	6.42	10.22	4.00	5.10	5.48	8.81	2.35	2.79	3.19	5.15
S5	6.01	6.30	8.10	17.12	4.29	7.30	7.65	10.55	4.19	5.90	6.50	10.16	3.97	5.34	5.58	8.83	2.29	2.81	3.26	5.09
Average compressive strength (MPa)	5.96	6.25	8.02	17.09	4.33	7.32	7.60	10.55	4.17	5.89	6.42	10.02	3.99	5.24	5.52	8.81	2.31	2.78	3.26	5.18

Table 20 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	7.95	9.12	12.89	18.56	7.44	8.94	12.19	16.70	7.85	8.87	10.28	15.70	6.76	8.43	10.44	12.32	3.87	4.06	5.99	9.07
S2	8.03	9.07	12.86	18.77	7.58	8.80	11.83	16.46	7.64	8.86	9.62	15.81	6.64	8.70	9.93	12.48	3.99	4.15	5.92	9.02
S3	8.00	9.09	12.78	18.75	7.46	8.92	11.90	16.55	7.68	8.84	9.78	15.76	6.68	8.55	9.98	12.50	3.86	4.12	5.56	8.56
S4	8.05	9.11	12.85	18.59	7.52	8.79	11.86	16.65	7.72	8.89	9.96	15.74	6.80	8.64	10.10	12.26	3.90	4.10	5.90	9.00
S5	8.01	9.06	12.83	18.78	7.56	8.96	12.12	16.60	7.76	8.85	10.15	15.72	6.94	8.68	10.08	12.36	3.95	4.04	5.54	8.65
Average compressive strength (MPa)	8.01	9.09	12.84	18.69	7.51	8.88	11.98	16.59	7.73	8.86	9.96	15.75	6.76	8.60	10.11	12.38	3.91	4.09	5.78	8.86

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Table 21 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	7.64	8.20	10.51	12.33	6.17	7.59	9.29	9.96	3.50	4.13	8.01	8.29	2.94	5.88	10.15	12.04
S2	7.99	8.04	10.20	12.34	6.26	7.64	9.19	9.75	3.59	4.17	7.42	7.89	2.73	5.87	10.32	11.87
S3	7.75	8.01	10.29	12.36	6.21	7.68	9.22	9.80	3.55	4.20	7.47	7.92	2.77	5.90	10.34	11.85
S4	7.80	8.10	10.34	12.38	6.18	7.71	9.24	9.86	3.60	4.24	7.89	8.10	2.80	6.05	10.20	12.01
S5	7.86	8.16	10.38	12.29	6.20	7,69	9.27	9.92	3.51	4.22	8.06	8.17	2.88	6.01	10.25	11.89
Average compressive strength (MPa)	7.81	8.10	10.34	12.34	6.20	7.66	9.24	9.86	3.55	4.19	7.77	8.07	2.82	5.94	10.25	11.93

Table 22 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	4.60	5.88	10.15	12.04	3.38	3.80	8.60	8.69	1.59	2.86	5.88	6.32
S2	4.57	5.87	10.32	11.82	3.40	3.71	8.34	8.62	1.52	2.89	5.61	5.80
S3	4.59	5.90	10.18	11.89	3.49	3.78	8.45	8.60	1.56	2.94	5.65	6.30
S4	4.62	5.94	10.24	11.86	3.46	3.75	8.52	8.68	1.55	2.97	5.90	6.34
S5	4.55	5.89	10.29	12.01	3.43	3.81	8.50	8.64	1.58	2.90	5.87	5.95
Average compressive strength (MPa)	4.59	5.90	10.24	11.92	3.43	3.77	8.48	8.65	1.56	2.91	5.78	6.14

Table 23 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	1.60	2.69	5.28	7.79	1.77	2.07	4.32	5.15
S2	1.64	2.79	5.32	7.62	1.70	1.99	4.24	5.19
S3	1.67	2.73	5.43	7.66	1.69	2.01	4.29	5.16
S4	1.62	2.70	5.40	7.69	1.74	2.09	4.27	5.14
S5	1.69	2.74	5.44	7.75	1.71	2.11	4.30	1.20
Average compressive strength (MPa)	1.64	2.73	5.37	7.70	1.72	2.05	4.28	4.37

Table 24 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	2.22	2.24	4.87	5.80
S2	2.37	2.42	4.77	5.95
S3	2.33	2.29	4.79	5.69
S4	2.28	2.32	4.82	5.75
S5	2.30	2.35	4.85	5.78
Average compressive strength (MPa)	2.30	2.32	4.82	5.79

Table 25 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

	Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																			
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	8.00	8.03	8.13	9.23	7.55	7.59	8.00	8.32	4.76	4.84	5.90	6.64	3.91	4.32	5.26	5.49	3.00	3.08	4.00	4.32
S2	7.84	7.90	8.05	9.26	7.47	7.61	8.04	8.15	4.62	4.89	5.86	6.40	3.70	4.39	5.20	5.40	2.97	3.10	4.06	4.39
S3	7.86	7.96	8.06	9.29	7.49	7.58	8.01	8.19	4.66	4.90	5.89	6.60	3.75	4.41	5.15	5.44	2.99	3.14	4.09	4.35
S4	7.89	7.99	8.09	9.29	4.52	7.60	8.05	8.26	4.69	4.86	5.84	6.65	3.79	4.50	5.17	5.47	2.97	3.17	4.12	4.40
S5	7.85	8.01	8.05	9.33	7.54	7.60	8.03	8.31	4.73	4.89	5.97	6.49	3.85	4.58	5.19	5.43	3.01	3.16	4.15	4.37
Average compressive strength (MPa)	7.39	7.98	8.08	9.28	6.91	7.60	8.03	8.25	4.69	4.88	5.89	6.56	3.80	4.44	5.19	5.45	2.99	3.13	4.08	4.37

Table 26 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	5.55	6.56	6.70	10.27	4.89	5.06	5.65	8.08	4.32	4.28	6.09	7.51	4.19	4.32	5.32	6.43	2.96	3.66	4.68	6.18
S2	5.49	6.09	6.79	9.98	4.91	5.01	5.38	8.10	4.20	4.40	5.52	7.42	4.04	4.33	5.20	6.26	2.82	3.61	4.70	6.15
S3	5.42	6.19	6.89	10.00	4.88	4.98	5.45	8.16	4.25	4.42	5.59	7.45	4.08	4.34	5.25	6.30	2.85	3.59	4.73	5.98
S4	5.50	6.25	6.90	10.25	4.90	4.99	5.50	8.26	4.30	4.39	5.55	7.49	4.10	4.30	5.28	6.35	2.90	3.56	4.69	6.00
S5	5.46	6.36	6.17	10.20	4.91	5.01	5.56	8.21	4.29	4.37	6.00	7.50	4.15	4.33	5.30	6.41	2.95	3.58	4.71	5.97
Average compressive strength (MPa)	5.48	6.29	6.69	10.14	4.90	5.01	5.51	8.16	4.27	4.37	5.75	7.47	4.11	4.32	5.27	6.35	2.90	3.60	4.70	6.06

Table 27 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Table 27 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)																
Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	5.95	6.75	8.38	8.93	3.61	5.19	5.43	6.78	3.22	4.90	4.95	6.08	3.08	3.63	4.42	5.37
S2	5.85	6.85	8.33	8.90	3.67	5.12	5.30	6.90	3.29	4.76	4.99	6.06	3.03	3.66	4.26	5.29
S3	5.90	6.79	7.89	8.92	3.69	5.07	5.36	7.03	3.35	4.81	5.04	6.01	3.06	3.69	4.29	5.32
S4	5.93	6.89	8.10	8.91	3.70	5.12	5.39	7.07	3.37	4.86	5.07	5.98	3.05	3.71	4.34	5.35
S5	5.88	6.86	8.13	8.90	3.68	5.10	5.42	7.00	3.38	4.89	5.06	6.00	3.02	3.71	4.41	5.38
Average compressive strength (MPa)	5.90	6.83	8.17	8.91	3.76	5.12	5.38	6.96	3.32	4.84	5.02	6.03	3.05	3.68	4.34	5.34

Table 28 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	4.32	6.97	7.22	8.58	3.93	5.79	6.03	7.20	3.43	4.61	4.69	5.76
S2	4.21	6.58	6.81	8.60	3.79	5.81	6.09	7.11	3.40	4.66	4.71	5.55
S3	4.25	6.62	6.87	9.10	3.81	5.94	6.06	7.14	3.34	4.62	4.77	5.59
S4	4.29	6.70	6.90	8.75	3.86	5.99	6.14	7.19	3.37	4.67	4.75	5.60
S5	4.31	6.69	7.00	8.72	3.91	5.96	6.13	7.17	3.39	4.65	4.76	5.71
Average compressive strength (MPa)	4.28	6.71	6.96	8.75	3.86	5.90	6.09	7.16	3.39	4.64	4.74	5.64

Table 29 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	3.45	5.49	5.79	6.51	3.09	4.69	4.77	5.80
S2	3.40	5.52	5.81	6.20	3.03	4.42	4.79	5.64
S3	3.33	5.56	5.85	6.25	2.95	4.49	4.85	5.69
S4	3.39	5.68	5.84	6.31	2.99	4.52	4.87	5.70
S5	3.42	5.66	5.80	6.40	3.06	4.50	4.86	5.78
Average compressive strength (MPa)	3.40	5.58	5.82	6.33	3.02	4.52	4.83	5.72

Table 30 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	2.54	3.71	4.23	4.27
S2	2.50	3.74	4.26	4.31
S3	2.51	3.79	4.21	4.29
S4	2.49	3.84	4.25	4.32
S5	2.55	3.86	4.24	4.30
Average compressive strength (MPa)	2.52	3.79	4.24	4.30

Table 31 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	8.95	15.40	17.29	17.65	8.84	16.22	15.54	16.04	8.47	12.84	14.18	14.55	6.71	9.87	11.51	11.77	4.05	4.61	4.63	5.51
S2	8.44	14.66	17.24	17.57	8.47	14.32	15.47	15.88	8.65	14.07	14.31	14.46	6.83	11.30	11.74	11.81	4.09	4.30	4.44	5.59
S3	8.49	14.69	17.20	17.59	8.50	14.39	15.49	15.86	8.50	12.87	14.20	14.43	6.79	9.90	11.57	11.86	4.12	4.35	4.47	5.60
S4	8.50	14.75	17.23	17.63	8.55	14.45	15.50	15.90	8.55	13.55	14.26	14.49	6.75	9.95	11.60	11.96	4.28	4.42	4.55	5.66
S5	8.90	14.84	17.18	17.61	8.59	14.50	15.51	16.20	8.62	13.59	14.35	14.42	6.90	10.95	11.67	11.97	4.25	4.55	4.60	5.64
Average compressive strength (MPa)	8.66	14.87	17.23	17.61	8.59	14.78	15.50	15.98	5.56	13.38	14.26	14.47	6.80	10.39	11.62	11.87	4.16	4.45	4.54	5.56

Table 32 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)																			
S1	10.01	14.86	15.19	15.47	8.43	12.11	12.29	12.33	9.62	11.16	11.68	11.84	7.84	9.81	9.93	10.03	4.43	4.99	5.35	5.52
S2	9.74	13.99	15.23	15.50	7.89	11.69	12.07	12.46	9.73	11.07	11.63	11.78	7.18	9.22	9.82	9.94	4.32	4.88	5.48	5.62
S3	9.80	14.25	14.81	15.54	7.90	11.75	12.11	12.38	9.60	11.09	11.65	11.76	7.24	9.29	9.86	9.98	4.37	4.90	5.39	5.55
S4	9.85	14.40	14.95	15.51	8.20	11.79	12.19	12.41	9.65	11.11	11.70	11.85	7.36	9.37	9.89	10.1	4.40	4.93	5.43	5.99
S5	9.95	14.55	15.00	15.00	8.35	11.85	12.23	12.43	9.50	11.14	11.67	11.80	7.50	9.45	9.90	9.99	4.41	4.96	5.46	5.60
Average compressive strength (MPa)	9.87	14.41	15.04	15.40	8.15	11.84	12.78	12.40	9.62	11.11	11.67	11.81	7.42	9.43	9.88	10.01	4.39	4.93	5.42	5.66

Table 33 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)															
S1	12.66	13.70	14.17	14.26	12.30	12.74	13.32	13.56	11.76	12.14	12.47	12.94	6.12	6.70	7.16	7.35
S2	12.93	13.74	14.24	14.40	12.43	12.66	13.30	13.44	11.79	12.12	12.27	12.97	6.15	6.71	7.39	7.49
S3	13.00	13.77	14.19	14.30	12.37	12.60	13.29	13.49	11.81	12.00	12.29	13.01	6.18	6.73	7.23	7.50
S4	13.05	14.01	14.23	14.36	12.39	12.59	13.22	13.53	11.84	12.13	12.30	13.15	6.21	6.69	7.34	7.36
S5	13.01	14.05	14.20	14.39	12.41	12.65	13.33	13.50	11.80	12.15	12.40	13.13	6.20	6.75	7.37	7.40
Average compressive strength (MPa)	12.93	13.85	14.21	14.34	12.38	12.65	13.29	13.50	11.80	12.08	12.35	13.04	6.17	6.72	7.30	7.42

Table 34 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)											
S1	9.32	10.15	11.00	11.14	8.66	9.76	10.09	10.50	3.21	4.77	4.93	4.94
S2	9.17	10.49	10.81	11.47	8.69	9.90	10.00	10.27	3.10	4.74	4.82	5.02
S3	9.23	10.20	10.84	11.25	8.72	9.81	10.03	10.34	3.09	4.75	4.88	4.95
S4	9.29	10.25	10.91	11.37	8.79	9.84	10.05	10.40	3.16	4.50	4.90	4.97
S5	9.30	10.34	10.97	11.45	8.65	9.75	10.07	10.45	3.24	4.73	4.92	4.99
Average compressive strength (MPa)	9.26	10.29	10.91	11.34	8.70	9.81	10.05	10.39	3.16	4.70	4.89	4.97

Table 35 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Compressive Strength (MPa)							
S1	6.86	6.89	7.61	7.93	3.69	5.57	5.56	5.60
S2	6.71	6.80	7.51	7.85	3.67	5.37	5.64	5.91
S3	6.77	6.83	7.57	7.87	3.57	5.39	5.62	5.65
S4	6.80	6.87	7.59	7.89	3.60	5.45	5.54	5.71
S5	6.85	6.85	7.60	7.84	3.63	5.50	5.60	5.79
Average compressive strength (MPa)	6.80	6.85	7.58	7.88	3.63	5.46	5.59	5.72

Table 36 Compressive strength of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Compressive Strength (MPa)			
S1	2.17	2.33	3.09	5.75
S2	2.06	2.22	2.93	5.67
S3	2.09	2.26	3.00	5.69
S4	2.10	2.29	3.04	5.70
S5	2.15	2.31	3.06	5.73
Average compressive strength (MPa)	2.11	2.28	3.02	5.71

ANNEXURE – III

Table 1 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	14.44	8.80	6.60	5.45	13.80	8.75	6.64	5.42	13.50	8.70	6.62	5.38	12.98	8.65	6.60	5.28
S2	14.60	8.85	6.80	5.50	13.75	8.77	6.60	5.40	13.45	8.72	6.60	5.36	12.80	8.62	6.57	5.24
S3	14.50	8.75	6.85	5.48	13.70	8.74	6.62	5.38	13.55	8.69	6.59	5.25	12.95	8.64	6.55	5.26
S4	14.65	8.84	6.82	5.46	13.76	8.70	6.64	5.44	13.50	8.71	6.60	5.28	13.00	8.55	6.58	5.20
S5	14.45	8.83	6.75	5.49	13.65	8.72	6.66	5.37	13.48	8.67	6.58	5.30	12.90	8.58	6.56	5.25
Average Water Absorption (%))	14.53	8.81	6.76	5.48	13.73	8.74	6.63	5.40	13.50	8.70	6.60	5.31	12.93	8.70	6.57	5.25

Contd………

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	10:25:65 (C:FA:IOW) (E)				05:30:65 (C:FA:IOW) (F)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	12.90	8.60	6.48	5.20	11.20	8.45	6.40	5.45
S2	11.98	8.58	6.44	5.18	11.50	8.48	6.42	5.50
S3	11.95	8.56	6.45	5.15	11.45	8.46	6.38	5.48
S4	11.85	8.52	6.50	5.17	11.48	8.50	6.36	5.46
S5	11.80	8.50	6.52	5.14	11.35	8.47	6.35	5.49
Average Water Absorption (%)	12.10	8.55	6.48	5.17	11.40	8.47	6.38	5.48

Table 2 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	14.45	8.78	6.85	5.43	13.70	8.75	6.82	5.36	13.54	8.72	6.78	5.35	12.96	8.71	6.69	5.30	12.84	8.60	6.70	5.23
S2	14.25	8.81	6.81	5.40	13.65	8.70	6.77	5.39	13.52	8.69	6.76	5.32	12.86	8.66	6.73	5.27	12.80	8.56	6.68	5.20
S3	14.20	8.83	6.78	5.44	13.68	8.76	6.74	5.41	13.50	8.67	6.74	5.29	12.89	8.62	6.71	5.29	12.83	8.59	6.66	5.19
S4	14.22	8.77	6.75	5.46	13.66	8.74	6.71	5.37	13.48	8.65	6.71	5.30	12.85	8.6	6.75	5.25	11.98	8.52	6.65	5.21
S5	14.36	8.80	6.79	5.40	13.69	8.71	6.73	5.35	13.51	8.70	6.73	5.34	12.90	8.63	6.70	5.22	12.00	8.50	6.62	5.25
Average Water Absorption (%)	14.30	8.80	6.80	5.43	13.68	8.73	6.75	5.38	13.51	8.69	6.74	5.32	12.89	8.64	6.72	5.27	12.49	8.55	6.66	5.22

Table 3 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	14.39	8.70	6.80	5.31	14.37	8.79	6.80	5.40	14.38	8.77	6.80	5.41	14.31	8.75	6.71	5.40
S2	14.37	8.82	6.83	5.29	14.35	8.76	6.77	5.36	14.36	8.80	6.72	5.49	14.27	8.71	6.70	5.40
S3	14.43	8.76	6.85	5.34	14.39	8.82	6.84	5.43	14.34	8.75	6.75	5.45	14.29	8.74	6.68	5.34
S4	14.40	8.8	6.81	5.32	14.36	8.80	6.76	5.39	14.31	8.74	6.71	5.44	14.25	8.76	6.65	5.36
S5	14.44	8.83	6.84	5.27	14.32	7.78	6.75	5.32	14.33	8.72	6.73	5.42	14.23	8.73	6.63	5.39
Average Water Absorption (%)	14.41	8.78	6.83	5.31	14.36	8.59	6.78	5.38	14.34	8.76	6.74	5.44	14.27	8.74	6.67	5.38

Table 4 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	14.35	8.68	6.79	5.39	14.26	8.65	6.71	5.31	14.20	8.57	6.67	5.30
S2	14.38	8.77	6.82	5.41	14.29	8.63	6.77	5.32	14.24	8.53	6.63	5.28
S3	14.30	8.73	6.77	5.37	14.30	8.69	6.76	5.36	14.22	8.60	6.70	5.33
S4	14.36	8.69	6.75	5.35	14.27	8.67	6.73	5.34	14.19	8.59	6.61	5.29
S5	14.31	8.75	6.80	5.40	14.23	8.61	6.75	5.30	14.17	8.54	6.89	5.26
Average Water Absorption (%)	14.34	8.72	6.79	5.38	14.27	8.65	6.74	5.33	14.20	8.57	6.70	5.29

Table 5 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	14.34	8.61	6.73	5.31	14.29	8.57	6.65	5.24
S2	14.30	8.65	6.70	5.29	14.25	8.51	6.63	5.22
S3	14.32	8.67	6.74	5.35	14.33	8.60	6.67	5.26
S4	14.27	8.59	6.67	5.30	14.28	8.57	6.61	5.25
S5	14.29	8.60	6.69	5.27	14.26	8.55	6.64	5.21
Average Water Absorption (%)	14.30	8.62	6.71	5.30	14.28	8.56	6.64	5.24

Table 6 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-1, SK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	14.10	8.26	6.55	5.09
S2	14.13	8.22	6.51	5.06
S3	14.07	8.20	6.57	5.02
S4	14.09	8.25	6.49	4.97
S5	14.05	8.29	6.53	4.99
Average Water Absorption (%)	14.09	8.24	6.53	5.03

Table 7 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

	Cement (C): Fly ash (FA) : Iron ore waste(IOW)																			
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.50	7.51	6.17	5.03	13.37	7.49	6.08	5.00	13.26	7.37	5.98	4.90	13.15	7.31	5.88	4.85	13.1	7.26	5.78	4.82
S2	13.48	7.60	6.20	5.10	13.39	7.50	6.10	5.01	13.29	7.35	6.01	4.93	13.20	7.30	5.90	4.90	13.13	7.24	5.80	4.79
S3	13.45	7.53	6.19	5.05	13.35	7.47	6.01	4.97	13.30	7.40	6.00	4.95	13.23	7.29	5.85	4.86	13.15	7.21	5.81	4.80
S4	13.40	7.55	6.15	5.09	13.33	7.45	6.06	4.99	13.25	7.33	5.93	4.91	13.17	7.35	5.89	4.89	13.11	7.25	5.76	4.77
S5	13.41	7.58	6.13	5.07	13.37	7.48	6.01	4.96	13.27	7.39	5.95	4.95	13.19	7.32	5.83	4.89	13.10	7.29	5.79	4.84
Average Water Absorption (%)	13.45	7.55	6.17	5.07	13.36	7.48	6.05	4.99	13.27	7.37	5.97	4.93	13.19	7.31	5.87	4.88	13.12	7.25	5.79	4.80

Table 8 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

	Cement (C): Fly ash (FA) : Iron ore waste(IOW)																			
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.37	7.46	6.04	4.97	13.25.	7.36	5.98	4.97	13.21	7.29	5.93	4.91	13.15	7.21	5.80	4.83	13.09	7.20	5.76	4.77
S2	13.40.	7.50	6.02	4.95	13.28	7.33	6.00	4.99	13.20.	7.32	5.90	4.95	13.17.	7.27	5.84	4.88	13.10	7.29	5.73	4.75
S3	13.35	7.43	6.10	5.01	13.30	7.40	6.02	5.00	13.19.	7.30	5.89	4.93	13.19	7.25	5.83	4.90	13.05	7.23	5.77	4.80
S4	13.33.	7.48	6.06	4.99	13.26	7.39	5.97	4.98	13.22.	7.33	5.91	4.95	13.13	7.23	5.87	4.85	13.07.	7.21	5.80	4.74
S5	13.39	7.49	6.09	4.96	13.29	7.38	5.99	5.01	13.19	7.27	5.88	4.94	13.15	7.25	5.86	4.87	13.09	7.20	5.79	4.79
Average Water Absorption (%)	13.37	7.47	6.06	4.98	13.28	7.37	5.92	4.99	13.20	7.30	5.90	4.94	13.16	7.24	5.84	4.87	13.08	7.23	5.77	4.77

Table 9 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	13.21	7.35	5.96	4.82	13.10	7.27	5.88	4.76	13.01	7.17	5.77	4.73	12.99	7.10	5.67	4.66
S2	13.25	7.33	6.00	4.85	13.15	7.30	5.91	4.80	13.06	7.19	5.80	4.70	12.97	7.15	5.70	4.69
S3	13.20	7.40	5.94	4.90	13.13	7.25	5.83	4.78	13.03	7.20	5.79	4.72	13.00	7.13	5.68	4.64
S4	13.18	7.37	5.97	4.87	13.17	7.29	5.85	4.75	13.10	7.15	5.74	4.71	12.95	7.11	5.66	4.70
S5	13.19	7.39	5.99	4.88	13.16	7.23	5.89	4.79	13.08	7.17	5.76	4.75	12.98	7.14	5.69	4.67
Average Water Absorption (%)	13.21	7.37	5.97	4.86	13.14	7.27	5.87	4.78	13.06	7.18	5.77	4.72	12.98	7.13	5.68	4.67

Table 10 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	13.11	7.29	5.90	4.82	13.06	7.20	5.85	4.73	13.00	7.15	5.83	4.7
S2	13.15	7.31	5.94	4.85	13.09	7.23	5.87	4.72	12.98	7.11	5.85	4.68
S3	13.13	7.33	5.92	4.8	13.03	7.19	5.89	4.77	12.97	7.17	5.8	4.71
S4	13.10	7.27	5.89	4.86	13.10	7.21	5.83	4.79	12.94	7.14	5.79	4.66
S5	13.15	7.25	5.90	4.85	13.05	7.20	5.85	4.75	12.99	7.1	5.82	4.69
Average Water Absorption (%)	13.13	7.29	5.91	4.84	13.07	7.21	5.86	4.75	12.98	7.13	5.82	13.13

Table 11 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	13.00	7.16	5.81	4.75	12.95	7.07	5.76	4.70
S2	13.05	7.20	5.88	4.77	12.92	7.05	5.79	4.73
S3	12.99	7.11	5.85	4.78	12.97	7.10	5.74	4.69
S4	13.04	7.15	5.83	4.80	12.91	7.09	5.8	4.71
S5	13.01	7.19	5.80	4.77	12.95	7.05	5.76	4.68
Average Water Absorption (%)	13.02	7.162	5.83	4.77	12.9	7.07	5.77	4.70

Table 12 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-2, KMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	12.86	7.00	5.68	4.60
S2	12.90	7.03	5.70	4.65
S3	12.84	7.05	5.30	4.63
S4	12.82	6.99	5.65	4.58
S5	12.80	7.00	5.70	4.60
Average Water Absorption (%)	12.84	7.01	5.61	4.61

Table 13 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	12.10	7.55	5.83	5.01	11.98	7.40	5.72	4.91	11.91	7.30	5.59	4.79	11.80	7.20	5.51	4.72	11.65	7.11	5.4	4.58
S2	12.15	7.50	5.85	4.97	12.00	7.45	5.71	4.90	11.95	7.27	5.60	4.81	11.83	7.17	5.49	4.70	11.69	7.13	5.42	4.60
S3	12.13	7.53	5.80	4.99	12.03	7.42	5.66	4.86	11.88	7.22	5.55	4.76	11.77	7.19	5.46	4.75	11.67	7.08	5.37	4.51
S4	12.07	7.48	5.78	4.93	11.96	7.39	5.69	4.89	11.85	7.25	5.57	4.78	11.75	7.15	5.50	4.68	11.71	7.1	5.35	4.55
S5	12.09	7.50	5.81	4.95	11.99	7.37	5.70	4.85	11.90	7.29	5.61	4.80	11.79	7.20	5.45	4.66	11.70	7.06	5.31	4.57
Average Water Absorption (%)	12.11	7.51	5.81	4.97	11.99	7.41	5.70	4.88	11.90	7.27	5.58	4.788	11.79	7.18	5.48	4.70	11.68	7.10	5.37	4.56

Table 14 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	11.97	7.31	5.69	4.86	11.88	7.20	5.57	4.76	11.71	7.01	5.43	4.66	11.62	6.93	5.37	4.55	11.66	6.78	5.19	4.39
S2	11.93	7.35	5.72	4.88	11.85	7.11	5.61	4.73	11.79	7.03	5.50	4.69	11.66	6.95	5.31	4.59	11.61	6.81	5.15	4.45
S3	12.00	7.30	5.70	4.84	11.90	7.19	5.55	4.79	11.75	7.00	5.47	4.61	11.69	6.90	5.33	4.53	11.69	6.85	5.16	4.49
S4	11.95	7.28	5.66	4.80	11.82	7.15	5.59	4.7	11.78	7.07	5.45	4.63	11.71	6.97	5.30	4.50	11.65	6.83	5.10	4.51
S5	12.01	7.26	5.63	4.82	11.91	7.17	5.53	4.75	11.80	7.06	5.41	4.60	11.70	6.95	5.29	4.52	11.60	6.79	5.13	4.40
Average Water Absorption (%)	11.97	7.30	5.68	4.84	11.87	7.16	5.57	4.75	11.77	7.03	5.45	4.64	11.68	6.94	5.32	4.54	11.64	6.81	5.15	4.45

Table 15 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	11.87	7.19	5.49	4.70	11.79	7.11	5.40	4.61	11.66	7.00	5.36	4.45	11.5	6.91	5.20	4.33
S2	11.91	7.22	5.59	4.72	11.76	7.03	5.43	4.55	11.69	6.97	5.30	4.48	11.57	6.88	5.24	4.37
S3	11.85	7.20	5.55	4.66	11.71	7.05	5.47	4.59	11.61	6.99	5.39	4.50	11.53	6.92	5.18	4.35
S4	11.82	7.15	5.51	4.69	11.75	7.09	5.49	4.62	11.63	7.02	5.35	4.52	11.59	6.85	5.26	4.39
S5	11.80	7.17	5.57	4.68	11.70	7.07	5.45	4.57	11.70	7.00	5.33	4.49	11.55	6.87	5.30	4.31
Average Water Absorption (%)	11.85	7.19	5.54	4.69	11.74	7.07	5.45	4.59	11.66	7.00	5.35	4.49	11.55	6.89	5.24	4.35

Table 16 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	11.71	7.11	5.32	4.55	11.60	6.00	5.23	4.37	11.45	5.95	5.10	4.33
S2	11.75	6.06	5.35	4.47	11.64	6.03	5.25	4.40	11.40	5.93	5.15	4.30
S3	11.69	7.10	5.30	4.45	11.57	5.97	5.20	4.39	11.47	5.90	5.13	4.35
S4	11.73	6.09	5.27	4.51	11.55	5.99	5.18	4.35	11.41	5.91	5.08	4.29
S5	11.66	6.08	5.29	4.53	11.58	6.01	5.23	4.41	11.44	5.94	5.11	4.31
Average Water Absorption (%)	11.71	6.49	5.31	4.502	11.59	6.00	5.22	4.38	11.43	5.93	5.11	4.32

Table 17 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	11.57	6.00	5.20	4.39	11.45	5.87	5.11	4.26
S2	11.6	6.01	5.17	4.37	11.47	5.91	5.13	4.23
S3	11.55	5.97	5.19	4.40	11.50	5.89	5.10	4.29
S4	11.59	5.99	5.21	4.35	11.43	5.90	5.15	4.27
S5	11.53	6.00	5.17	4.38	11.41	5.93	5.10	4.30
Average Water Absorption (%)	11.57	5.99	5.19	4.38	11.45	5.90	5.12	4.27

Table 18 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-3, NK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	11.31	5.69	4.96	4.01
S2	11.35	5.78	5	4.03
S3	11.27	5.73	4.99	4.10
S4	11.29	5.77	4.95	4.05
S5	11.33	5.75	4.91	4.09
Average Water Absorption (%)	11.31	5.74	4.96	4.06

Table 19 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	14.09	8.31	6.43	5.01	14.02	8.3	6.4	4.98	13.86	8.20	6.30	4.90	13.76	8.11	6.10	4.81	13.66	7.96	5.97	4.70
S2	14.01	8.37	6.47	5.06	13.96	8.33	6.44	4.96	13.85	8.23	6.27	4.86	13.73	8.13	6.13	4.77	13.71	7.93	5.95	4.72
S3	14.05	8.35	6.5	5.05	13.94	8.35	6.37	5.00	13.91	8.25	6.33	4.92	13.81	8.17	6.20	4.80	13.69	8.10	5.99	4.74
S4	14.07	8.3	6.49	5.03	14. 00	8.27	6.35	4.95	13.83	8.19	6.25	4.83	13.79	8.19	6.11	4.75	13.65	7.98	6.10	4.71
S5	14.03	8.34	6.45	5.02	13.92	8.29	6.33	4.93	13.8	8.21	6.21	4.84	13.74	8.10	6.17	4.79	13.63	7.95	5.93	4.69
Average Water Absorption (%)	14.05	8.33	6.47	5.03	13.97	8.308	6.38	4.96	13.85	8.22	6.27	4.87	13.77	8.14	6.14	4.78	13.67	7.98	5.99	4.71

Table 20 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.97	8.29	6.38	4.97	13.86	8.16	6.30	4.85	13.84	8.13	6.26	4.79	13.77	8.01	6.18	4.7	13.66	8.00	6.10	4.61
S2	13.94	8.23	6.41	4.95	13.89	8.18	6.36	4.87	13.88	8.10	6.24	4.75	13.74	8.05	6.15	4.67	13.64	7.97	6.07	4.63
S3	13.99	8.25	6.35	5.00	13.91	8.20	6.33	4.81	13.83	8.07	6.21	4.80	13.71	8.09	6.11	4.69	13.70	7.99	6.09	4.60
S4	13.91	8.21	6.39	4.93	13.90	8.15	6.37	4.83	13.8	8.09	6.20	4.73	13.79	8.07	6.10	4.65	13.61	7.95	6.02	4.57
S5	13.93	8.26	6.40	4.90	13.85	8.13	6.39	4.80	13.82	8.11	6.25	4.71	13.80	8.03	6.14	4.63	13.69	7.99	6.05	4.59
Average Water Absorption (%)	13.95	8.25	6.39	4.95	13.88	8.16	6.35	4.83	13.83	8.10	6.23	4.76	13.76	8.05	6.14	4.67	13.66	7.98	6.07	4.60

Table 21 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	13.90	8.20	6.36	4.88	13.81	8.10	6.29	4.79	13.71	8.01	6.17	4.70	13.57	7.93	6.00	4.55
S2	13.87	8.17	6.31	4.81	13.77	8.08	6.27	4.76	13.75	7.99	6.19	4.66	13.59	7.90	5.97	4.49
S3	13.89	8.12	6.34	4.85	13.80	8.11	6.30	4.73	13.76	8.05	6.20	4.69	13.55	7.91	6.01	4.50
S4	13.85	8.15	6.39	4.82	13.75	8.06	6.25	4.80	13.73	8.00	6.15	4.65	13.60	7.88	5.95	4.47
S5	13.84	8.13	6.32	4.87	13.79	8.09	6.23	4.75	13.70	8.03	6.13	4.61	13.56	7.86	5.99	4.51
Average Water Absorption (%)	13.87	8.15	6.34	4.85	13.78	8.09	6.27	4.77	13.73	8.02	6.17	4.66	13.57	7.90	5.98	4.50

Table 22 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	13.81	8.07	6.28	4.76	13.7	8.00	6.24	4.70	13.60	7.87	6.09	4.63
S2	13.78	8.05	6.30	4.79	13.68	8.05	6.20	4.68	13.58	7.89	6.00	4.65
S3	13.82	8.10	6.25	4.74	13.73	7.93	6.17	4.72	13.65	7.93	6.15	4.69
S4	13.75	8.09	6.23	4.80	13.66	7.98	6.19	4.67	13.63	7.90	6.07	4.61
S5	13.77	8.11	6.29	4.81	13.69	7.99	6.21	4.71	13.59	7.85	6.13	4.66
Average Water Absorption (%)	13.79	8.08	6.27	4.78	13.69	7.99	6.20	4.70	13.61	7.89	6.09	4.65

Table 23 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	13.66	8.00	6.17	4.69	13.57	7.90	6.10	4.60
S2	13.60	7.97	6.15	4.72	13.54	7.96	6.13	4.57
S3	13.69	7.99	6.21	4.75	13.57	7.96	6.08	4.62
S4	13.70	8.03	6.19	4.67	13.60	7.89	6.11	4.59
S5	13.64	8.01	6.20	4.65	13.59	7.91	6.06	4.55
Average Water Absorption (%)	13.66	8.00	6.18	4.70	13.57	7.92	6.10	4.59

Table 24 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-4, Ankamnal)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	13.56	7.90	6.10	4.59
S2	13.59	7.87	6.08	4.62
S3	13.53	7.89	6.12	4.64
S4	13.60	7.91	6.05	4.57
S5	13.57	7.85	6.07	4.60
Average Water Absorption (%)	13.57	7.88	6.08	4.60

Table 25 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

	Cement (C): Fly ash (FA) : Iron ore waste(IOW)																			
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.88	8.20	6.71	5.16	13.8	8.10	6.60	5.10	13.67	8.01	6.56	5.06	13.6	7.98	6.50	4.96	13.49	7.91	6.40	4.89
S2	14.00	8.25	6.73	5.14	13.74	8.13	6.59	5.12	13.69	8.04	5.59	5.05	13.62	8.00	6.48	5.00	13.47	7.88	6.37	4.91
S3	13.86	8.23	6.75	5.20	13.76	8.15	6.65	5.09	13.70	8.00	6.56	5.01	13.57	7.99	6.51	4.98	13.5	7.90	6.41	4.85
S4	13.89	8.19	6.67	5.21	13.79	8.09	6.63	5.06	13.65	8.02	6.55	5.00	13.55	7.97	6.46	4.97	13.53	7.85	6.35	4.87
S5	13.87	8.20	6.69	5.19	13.80	8.10	6.61	5.11	13.71	8.05	6.51	5.03	13.59	8.96	6.49	4.95	13.49	7.89	6.39	4.90
Average Water Absorption (%)	13.90	8.21	6.71	5.18	13.78	8.11	6.62	5.10	13.68	8.02	6.35	5.03	13.59	8.18	6.49	4.97	13.50	7.89	6.38	4.88

Table 26 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.80	8.10	6.60	5.10	13.71	8.03	6.55	5.01	13.60	8.00	6.48	4.92	13.50	7.91	6.37	4.85	13.4	7.78	6.31	4.76
S2	13.82	8.14	6.65	5.12	13.73	8.00	6.51	4.99	13.57	7.96	6.50	4.95	13.53	7.87	6.39	4.88	13.45	7.82	6.33	4.74
S3	13.76	8.12	6.63	5.08	13.69	8.09	6.53	5.02	13.61	7.99	6.46	4.90	13.51	7.90	6.40	4.81	13.43	7.80	6.27	4.79
S4	13.74	8.08	6.59	5.06	13.64	8.06	6.57	4.97	13.63	7.94	6.44	4.89	13.47	7.85	6.35	4.80	13.39	7.75	6.29	4.71
S5	13.79	8.10	6.64	5.11	13.66	8.01	6.55	5.00	13.59	7.92	6.42	4.90	13.49	7.88	6.38	4.83	13.40	7.79	6.30	4.70
Average Water Absorption (%)	13.78	8.11	6.62	5.09	13.69	8.04	6.54	5.0	13.60	7.96	6.46	4.91	13.50	7.88	6.38	4.83	13.41	7.79	6.30	4.74

Table 27 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	13.65	8.00	6.50	5.01	13.59	7.90	6.40	4.90	13.51	7.81	6.30	4.82	13.42	7.75	6.21	4.70
S2	13.70	8.02	6.52	4.96	13.62	7.93	6.45	4.88	13.48	7.84	6.33	4.8	13.38	7.77	6.16	4.66
S3	13.67	7.97	6.54	5.03	13.56	7.88	6.39	4.92	13.50	7.83	6.35	4.79	13.44	7.70	6.19	4.69
S4	13.69	7.99	6.47	4.95	13.58	7.91	6.43	4.86	13.46	7.79	6.29	4.76	13.34	7.73	6.14	4.63
S5	13.64	7.95	6.49	4.99	13.54	7.86	6.37	4.89	13.49	7.80	6.31	4.72	13.30	7.69	6.18	4.60
Average Water Absorption (%)	13.67	7.99	6.504	4.99	13.58	7.90	6.41	4.89	13.49	7.82	6.32	4.78	13.38	7.73	6.18	4.66

28 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	13.51	7.90	6.31	4.80	13.43	7.81	6.23	4.72	13.33	7.69	6.11	4.61
S2	13.55	7.85	6.35	4.82	13.45	7.77	6.20	4.69	13.26	7.65	6.07	4.63
S3	13.47	7.87	6.29	4.76	13.40	7.80	6.19	4.65	13.28	7.71	6.10	4.58
S4	13.50	7.89	6.30	4.79	13.38	7.75	6.21	4.67	13.23	7.67	6.03	4.54
S5	13.48	7.90	6.34	4.77	13.36	7.79	6.17	4.70	13.25	7.66	6.01	4.59
Average Water Absorption (%)	13.50	7.88	6.32	4.79	13.40	7.78	6.20	4.69	13.27	7.68	6.06	4.59

Table 29 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	13.41	7.80	6.23	4.71	13.30	7.75	6.06	4.63
S2	13.44	7.82	6.26	4.75	13.32	7.69	6.11	4.58
S3	13.40	7.77	6.21	4.73	13.26	7.72	6.09	4.61
S4	13.37	7.79	6.19	4.69	13.21	7.66	6.01	4.55
S5	13.39	7.80	6.17	4.70	13.28	7.64	6.04	4.60
Average Water Absorption (%)	13.40	7.80	6.21	4.72	13.27	7.69	6.06	4.59

Table 30 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-5, JLK-YRD)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	13.26	7.60	6.01	4.35
S2	13.30	7.65	6.05	4.50
S3	13.20	7.58	5.99	4.39
S4	13.27	7.63	6.03	4.46
S5	13.27	7.59	5.97	4.40
Average Water Absorption (%)	13.26	7.61	6.01	4.42

Table 31 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:05:65 (C:FA:IOW) (A)				25:10:65 (C:FA:IOW) (B)				20:15:65 (C:FA:IOW) (C)				15:20:65 (C:FA:IOW) (D)				10:25:65 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.88	7.99	6.31	5.21	13.81	7.90	6.25	5.10	13.69	7.80	6.12	5.00	13.56	7.77	6.01	4.96	13.50	7.71	5.96	4.88
S2	13.80	7.96	6.39	5.19	13.77	7.86	6.27	5.15	13.66	7.78	6.10	5.05	13.58	7.72	6.05	5.00	13.47	7.68	5.94	4.85
S3	13.85	8.00	6.40	5.25	13.79	7.94	6.30	5.16	13.70	7.84	6.19	5.08	13.60	7.75	6.10	4.91	13.45	7.65	6.00	4.90
S4	13.83	7.97	6.36	5.23	13.75	7.89	6.21	5.19	13.64	7.81	6.15	5.06	13.54	7.79	6.03	4.93	13.43	7.70	5.93	4.84
S5	13.87	7.95	6.34	5.20	13.73	7.91	6.29	5.15	13.69	7.82	6.17	5.01	13.52	7.74	6.08	4.98	13.49	7.62	5.98	4.81
Average Water Absorption (%)	13.85	7.97	6.36	5.22	13.77	7.90	6.26	5.15	13.68	7.81	6.15	5.04	13.56	7.75	6.05	4.96	13.47	7.67	5.96	4.86

Table 32 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																				
Proportion of material	30:00:70 (C:FA:IOW) (A)				25:05:70 (C:FA:IOW) (B)				20:10:70 (C:FA:IOW) (C)				15:15:70 (C:FA:IOW) (D)				10:20:70 (C:FA:IOW) (E)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)																			
S1	13.70	7.86	6.19	5.07	13.61	7.80	6.11	5.03	13.49	7.78	6.06	4.95	13.40	7.61	6.00	4.80	13.36	7.55	5.92	4.76
S2	13.73	7.89	6.20	5.09	13.63	7.86	6.17	4.98	13.53	7.75	6.01	4.90	13.43	7.63	5.97	4.85	13.30	7.57	5.90	4.71
S3	13.78	7.90	6.29	5.12	13.68	7.84	6.15	5.01	13.60	7.72	6.05	4.93	13.45	7.65	5.99	4.87	13.34	7.60	5.86	4.78
S4	13.75	7.84	6.25	5.10	13.65	7.81	6.13	4.96	13.50	7.79	6.08	4.97	13.49	7.67	6.01	4.82	13.29	7.61	5.84	4.75
S5	13.72	7.88	6.27	5.05	13.70	7.83	6.10	5.00	13.59	7.70	6.10	4.91	13.47	7.69	5.95	4.86	13.27	7.54	5.88	4.73
Average Water Absorption (%)	13.74	7.87	6.24	5.09	13.64	7.83	6.13	5.00	13.54	7.75	6.06	4.93	13.45	7.65	5.98	4.84	13.31	7.57	5.88	4.75

Table 33 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)																
Proportion of material	25:00:75 (C:FA:IOW) (A)				20:05:75 (C:FA:IOW) (B)				15:10:75 (C:FA:IOW) (C)				10:15:75 (C:FA:IOW) (D)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)															
S1	13.62	7.80	6.11	4.96	13.55	7.70	6.02	4.90	13.50	7.60	5.93	4.80	13.313	7.5	5.86	4.74
S2	13.65	7.76	6.13	4.94	13.6	7.72	6.07	4.93	13.48	7.63	5.91	4.82	13.33	7.52	5.84	4.71
S3	13.61	7.79	6.10	4.98	13.58	7.67	6.00	4.89	13.43	7.65	6.00	4.86	13.40	7.57	5.91	4.76
S4	13.67	7.82	6.16	5.01	13.52	7.69	6.05	4.91	13.46	7.61	5.95	4.81	13.36	7.55	5.81	4.70
S5	13.63	7.74	6.15	4.99	13.54	7.70	6.03	4.93	13.49	7.59	5.97	4.84	13.39	7.53	5.90	4.75
Average Water Absorption (%)	13.64	7.78	6.13	4.98	13.56	7.70	6.03	4.91	13.47	7.62	5.95	4.83	13.36	7.54	5.86	4.73

Table 34 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)												
Proportion of material	20:00:80 (C:FA:IOW) (A)				15:05:80 (C:FA:IOW) (B)				10:10:80 (C:FA:IOW) (C)			
No. of days for curing	7	14	21	28	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)											
S1	13.53	7.6	5.97	4.80	13.4	7.55	5.88	4.70	13.13	7.45	5.71	4.61
S2	13.50	7.65	5.94	4.84	13.42	7.51	5.9	4.75	13.35	7.48	5.80	4.65
S3	13.49	7.63	6.00	4.82	13.44	7.53	5.82	4.73	13.30	7.43	5.71	4.60
S4	13.56	7.59	5.99	4.77	13.39	7.50	5.86	4.69	13.28	7.41	5.73	4.59
S5	13.51	7.61	5.95	4.79	13.45	7.57	5.89	4.71	13.31	7.40	5.78	4.63
Average Water Absorption (%)	13.52	7.62	5.97	4.80	13.42	7.53	5.87	4.72	13.27	7.43	5.75	4.62

Table 35 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)								
Proportion of material	15:00:85 (C:FA:IOW) (A)				10:05:85 (C:FA:IOW) (B)			
No. of days for curing	7	14	21	28	7	14	21	28
Brick	Water Absorption (%)							
S1	13.37	7.49	5.82	4.70	13.30	7.42	5.76	4.71
S2	13.40	7.55	5.90	4.73	13.26	7.46	5.80	4.70
S3	13.35	7.48	5.80	4.71	13.27	7.44	5.79	4.69
S4	13.33	7.50	5.88	4.67	13.29	7.40	5.75	4.67
S5	13.39	7.52	5.86	4.69	13.22	7.45	5.77	4.70
Average Water Absorption (%))	13.37	7.51	5.85	4.70	13.27	7.43	5.77	4.69

Table 36 Water Absorption results of bricks prepared by iron ore waste, cement and fly ash (Sample-9, RMK)

Cement (C): Fly ash (FA) : Iron ore waste(IOW)				
Proportion of material	10:00:90 (C:FA:IOW) (A)			
No. of days for curing	7	14	21	28
Brick	Water Absorption (%)			
S1	13.30	7.45	5.77	4.61
S2	13.33	7.48	5.80	4.67
S3	13.35	7.44	5.75	4.65
S4	13.29	7.40	5.79	4.63
S5	13.31	7.43	5.74	4.60
Average Water Absorption (%)	13.32	7.44	5.77	4.63

ANNEXURE – IV

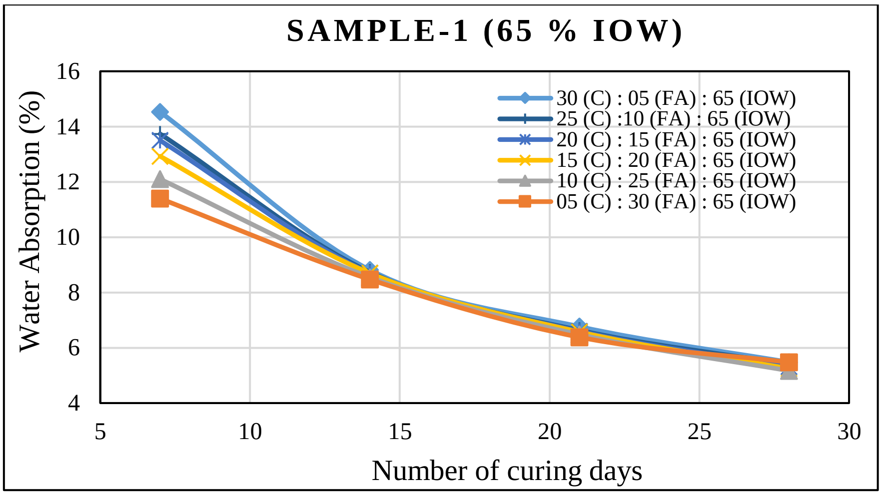

Fig. 1 Water absorption vs. number of curing days

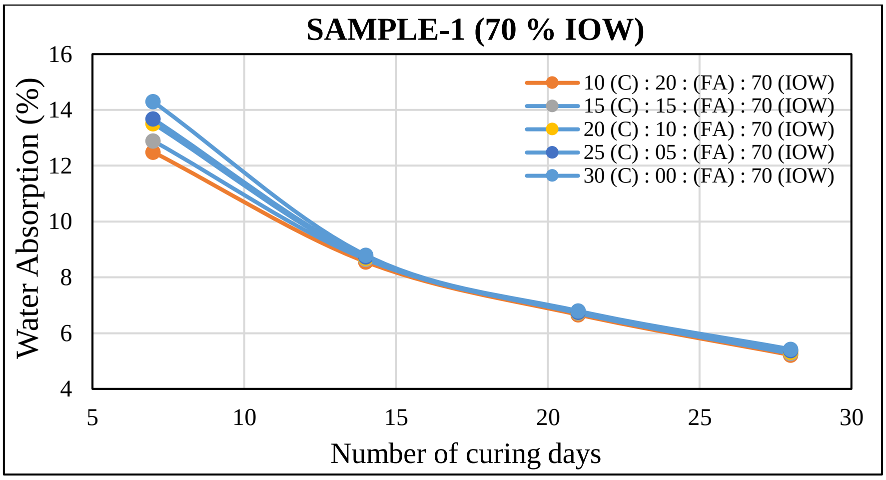

Fig. 2 Water absorption vs. number of curing days

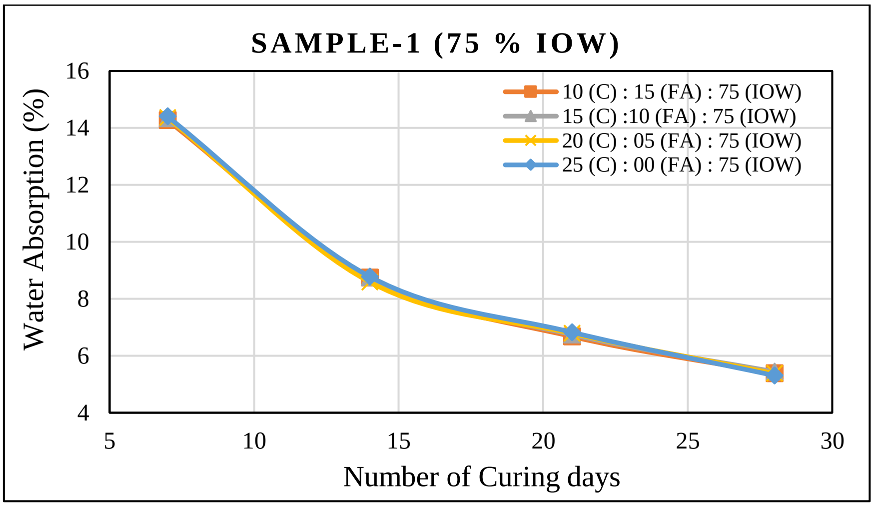

Fig. 3 Water absorption vs. number of curing days

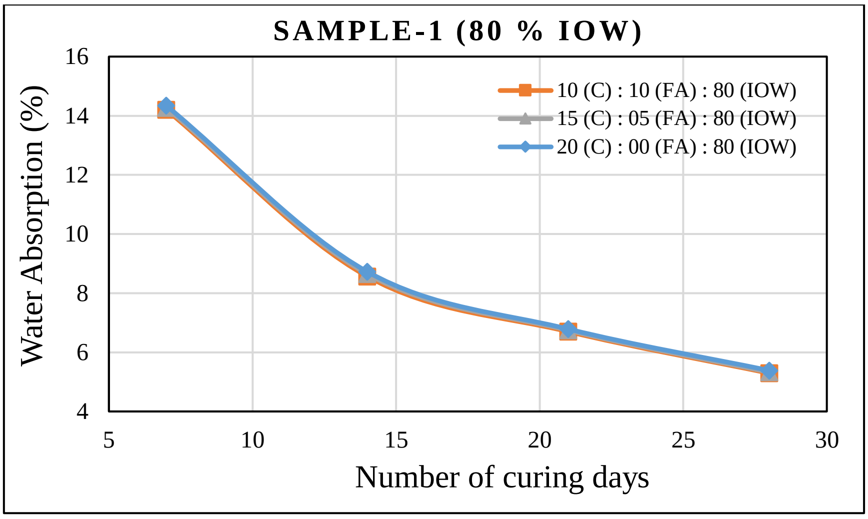

Fig. 4 Water absorption vs. number of curing days

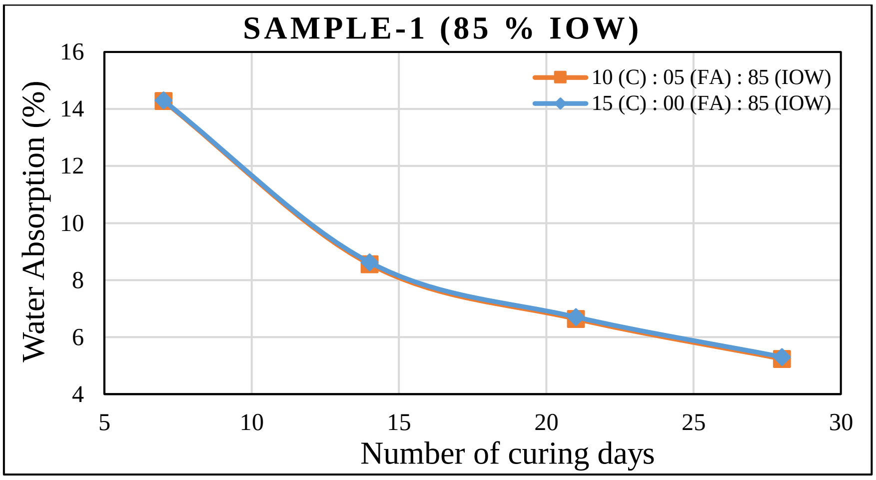

Fig. 5 Water absorption vs. number of curing days

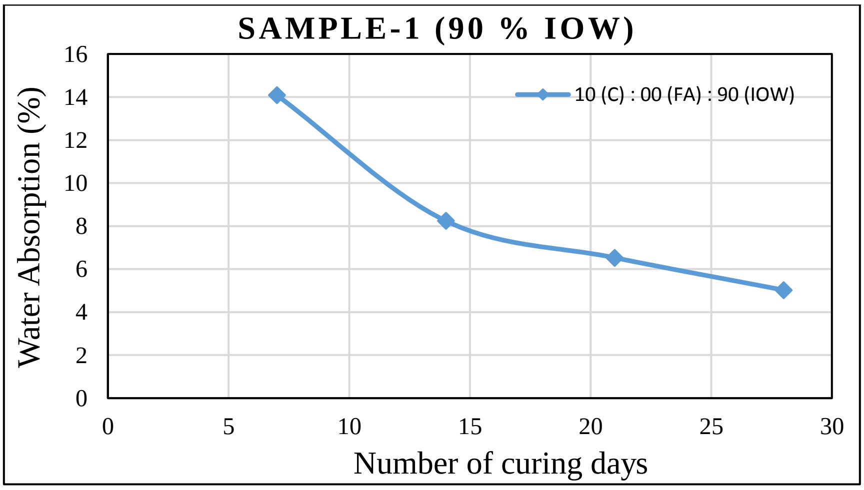

Fig. 6 Water absorption vs. number of curing days

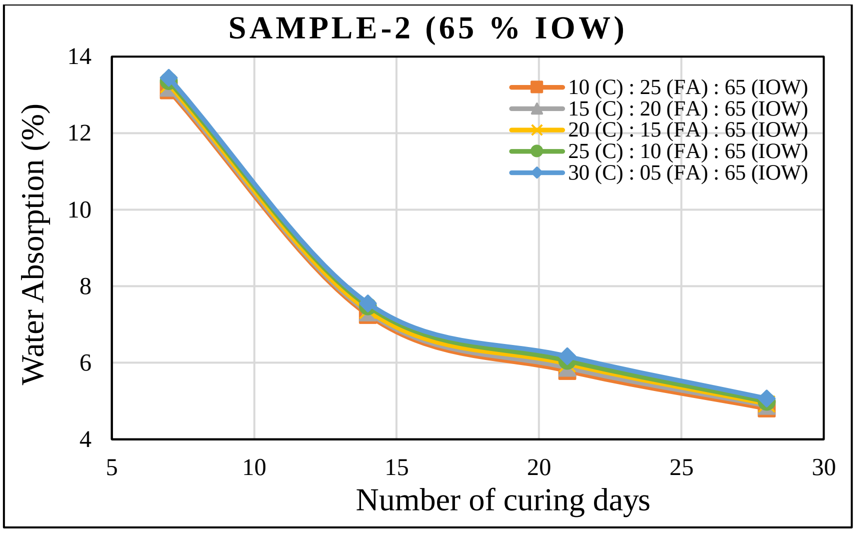

Fig. 7 Water absorption percentage vs. number of curing days

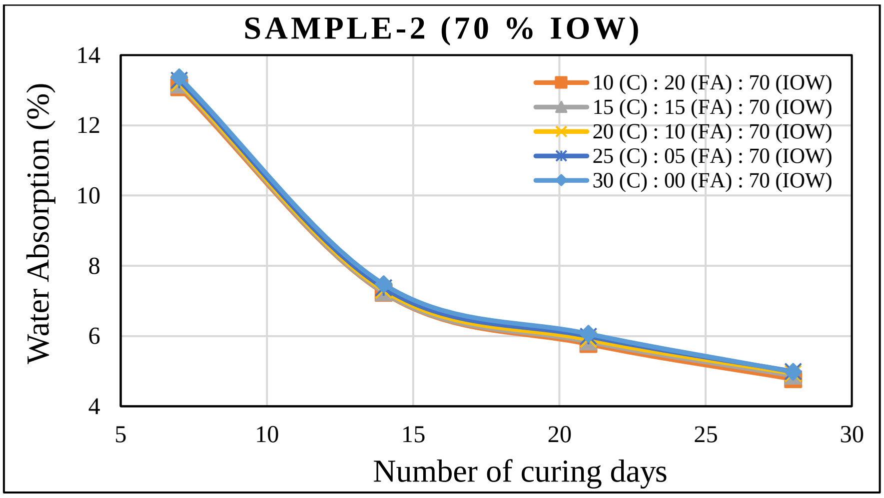

Fig. 8 Water absorption percentage vs. number of curing days

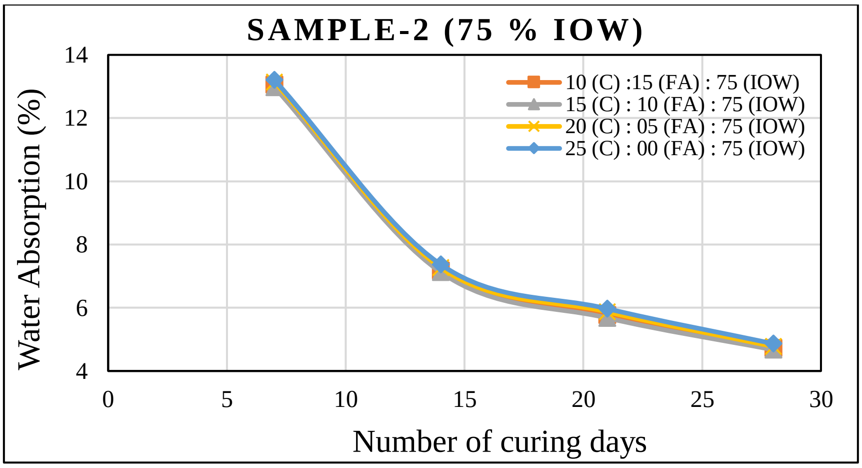

Fig. 9 Water absorption percentage vs. number of curing days

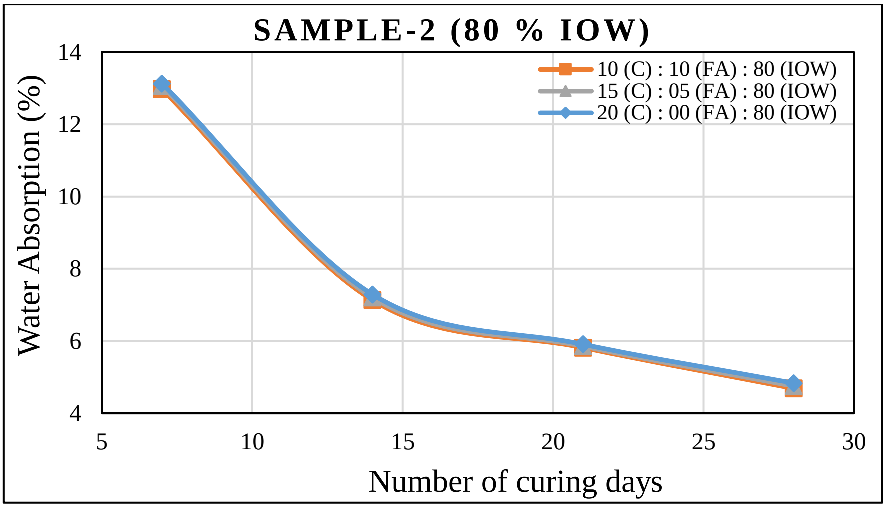

Fig. 10 Water absorption percentage vs. number of curing days

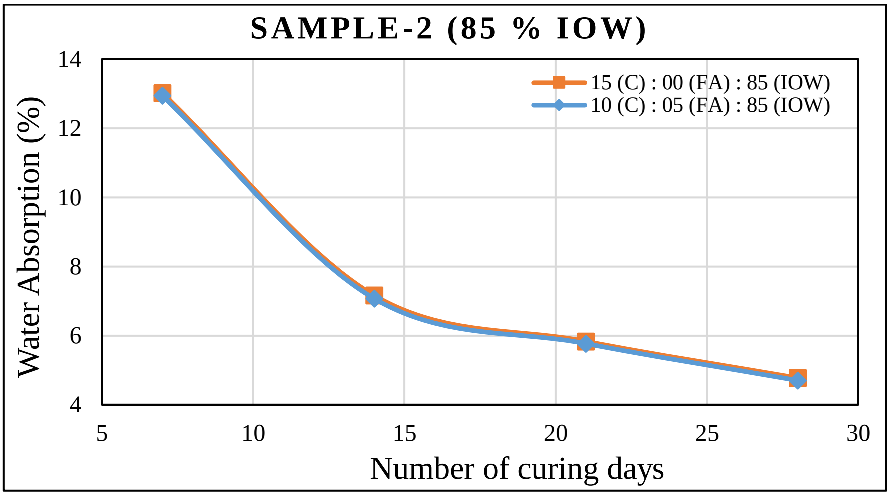

Fig. 11 Water absorption percentage vs. number of curing days

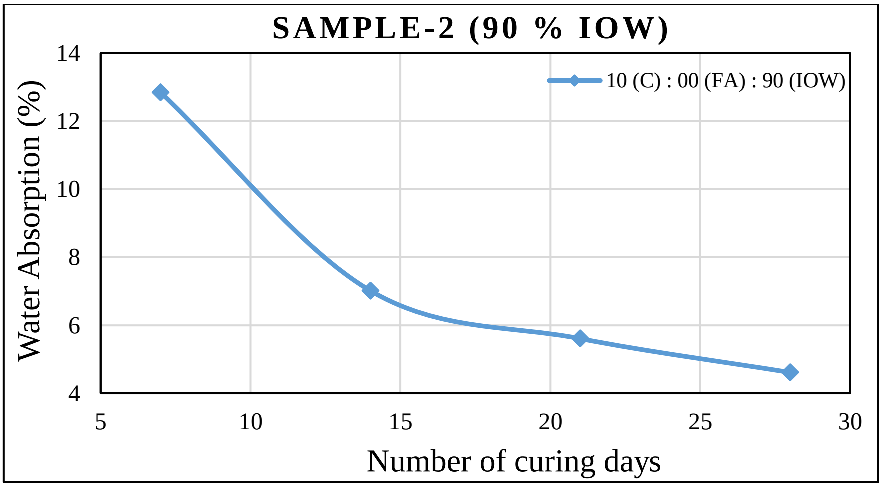

Fig. 12 Water absorption vs. number of curing days

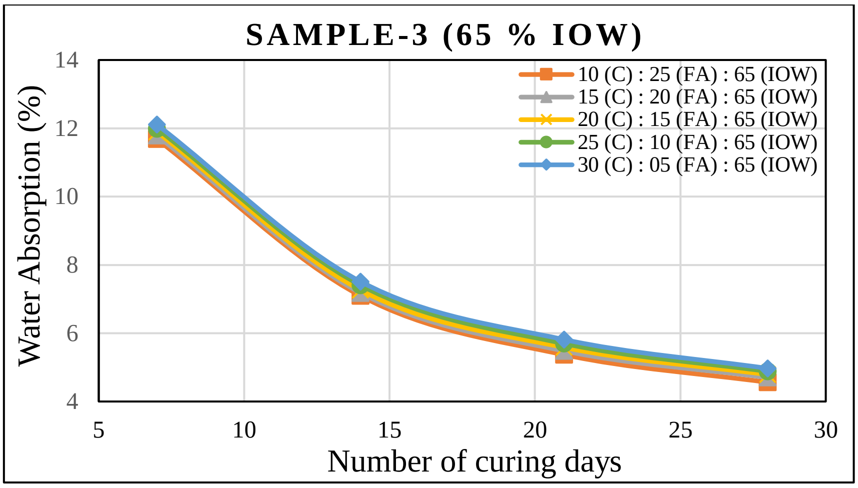

Fig. 13 Water absorption percentage vs. number of curing days

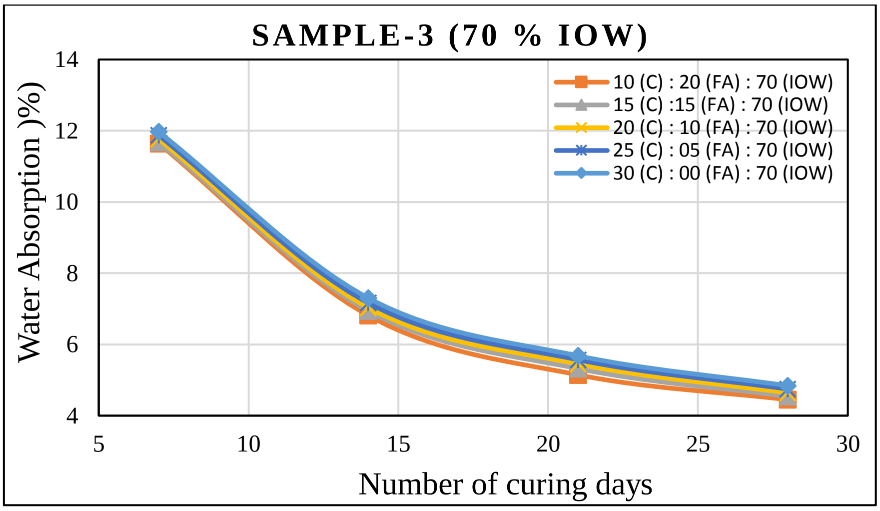

Fig. 14 Water absorption percentage vs. number of curing days

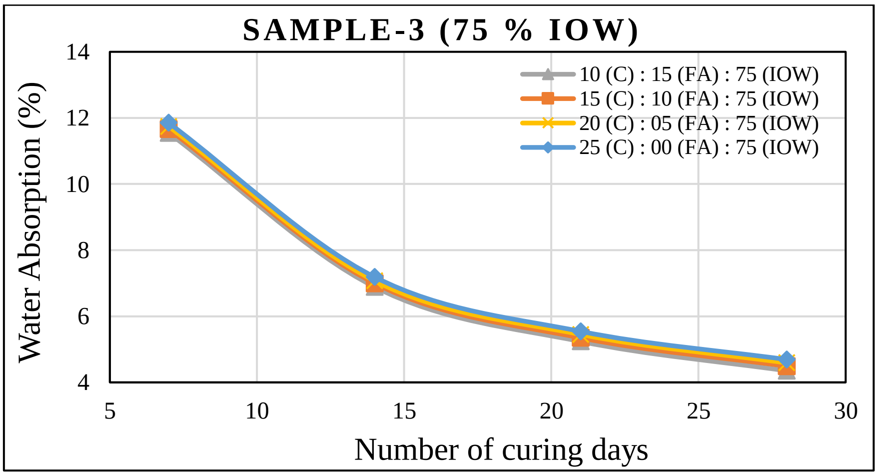

Fig. 15 Water absorption percentage vs. number of curing days

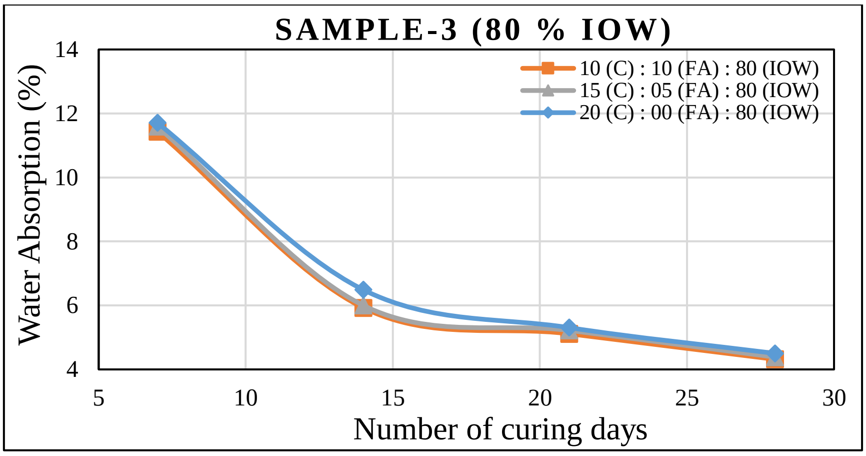

Fig. 16 Water absorption percentage vs. number of curing days

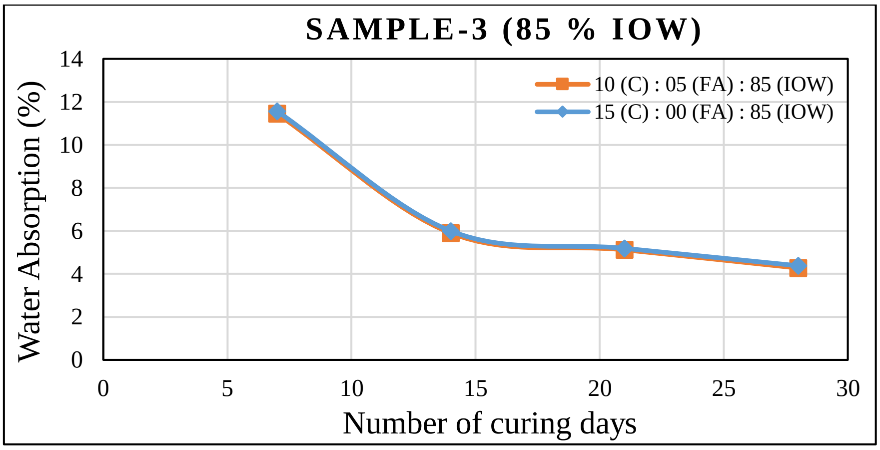

Fig. 17 Water absorption percentage vs. number of curing days

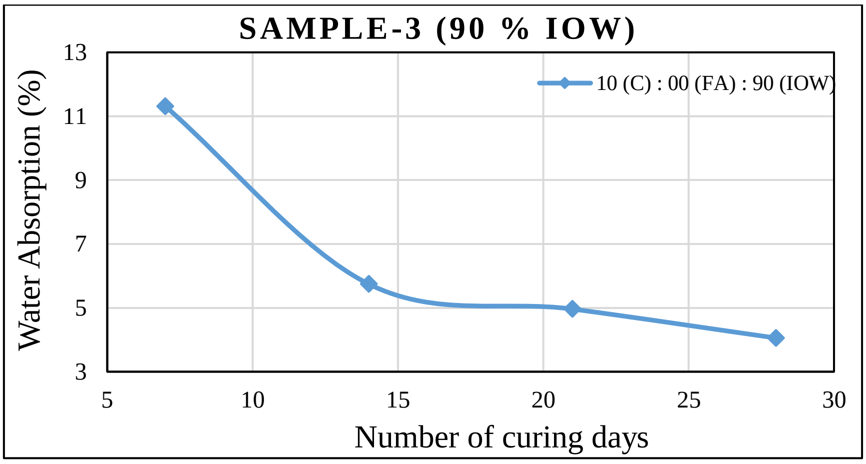

Fig. 18 Water absorption vs. number of curing days

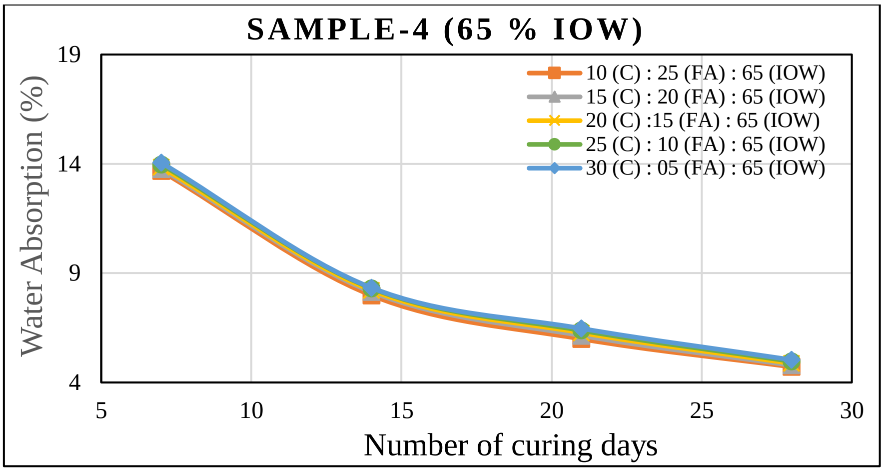

Fig. 19 Water absorption percentage vs. number of curing days

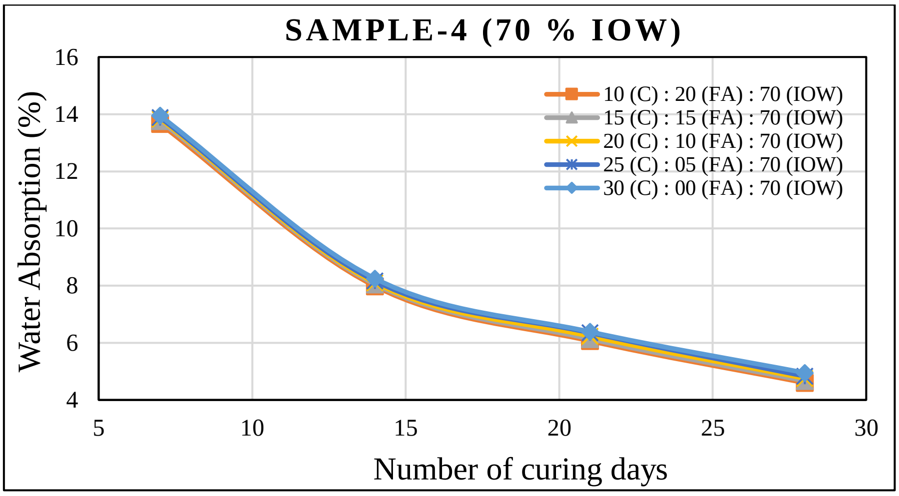

Fig. 20 Water absorption percentage vs. number of curing days

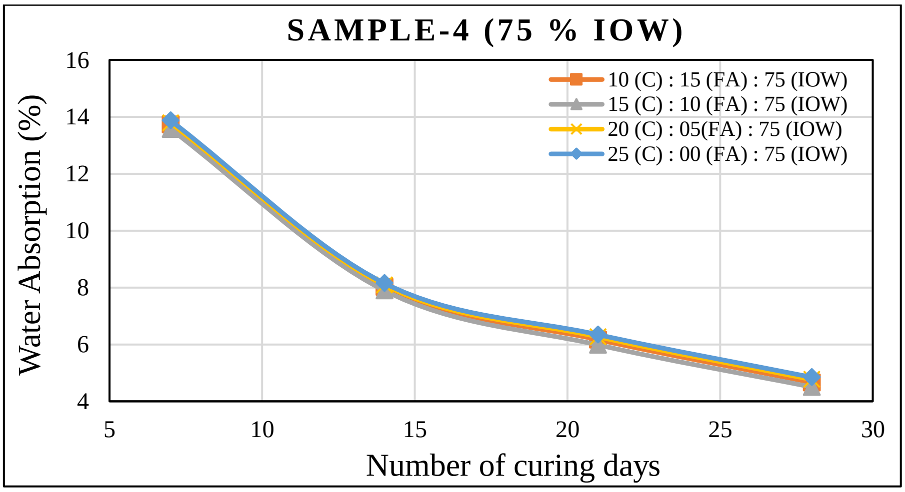

Fig. 21 Water absorption percentage vs. number of curing days

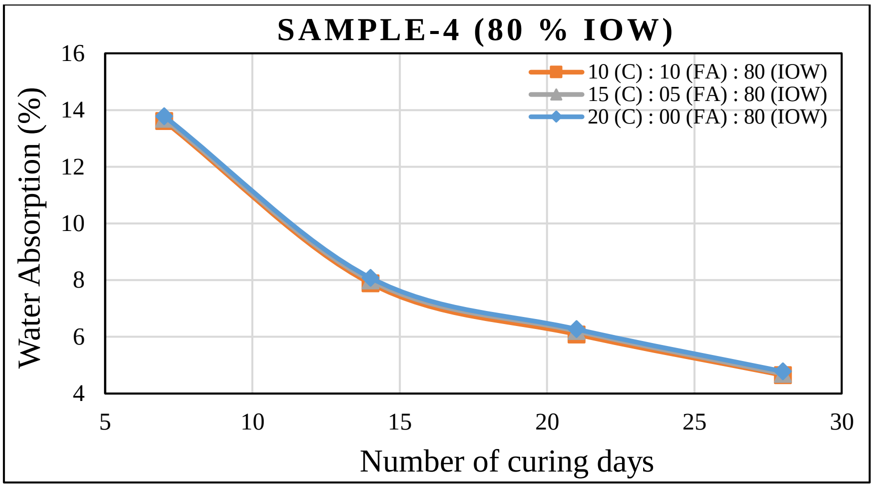

Fig. 22 Water absorption percentage vs. number of curing days

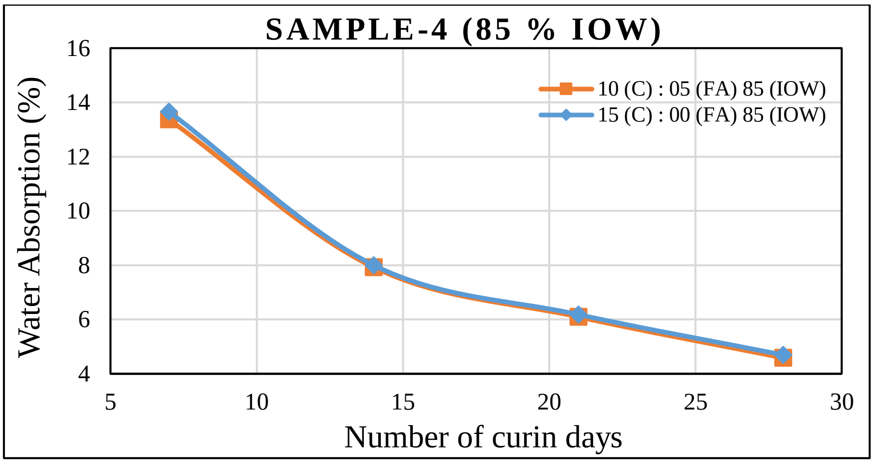

Fig. 23 Water absorption percentage vs. number of curing days

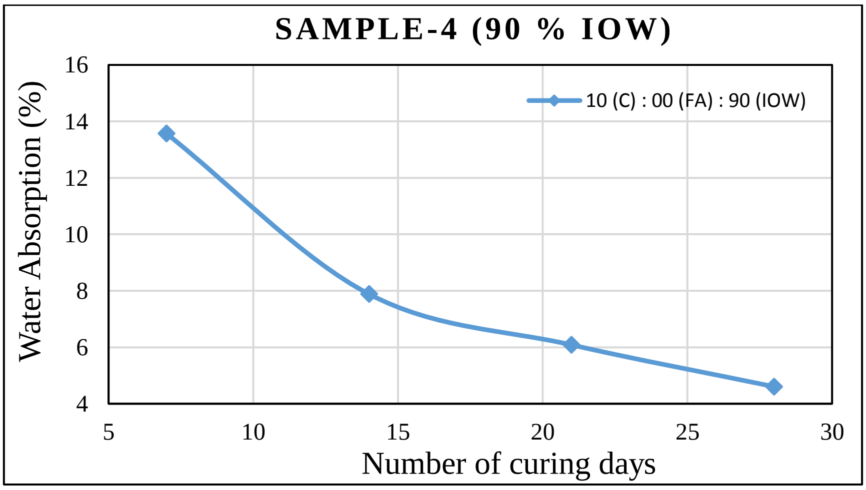

Fig. 24 Water absorption vs. number of curing days

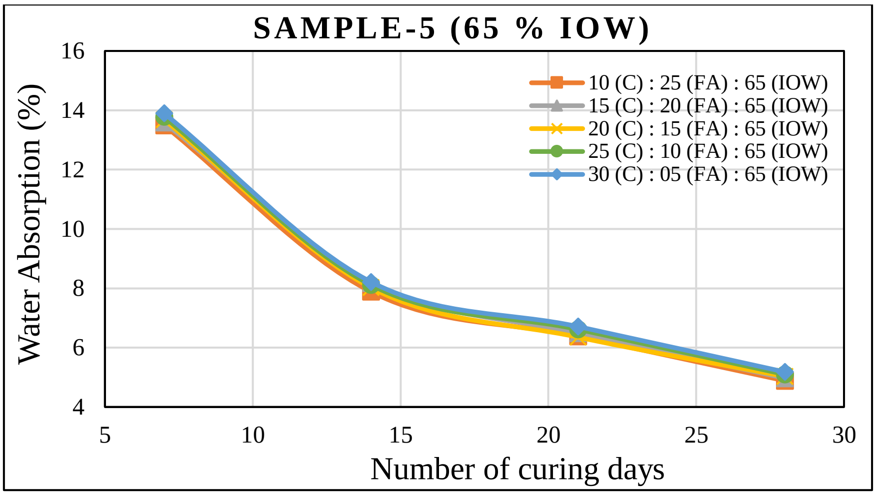

Fig. 25 Water absorption percentage vs. number of curing days

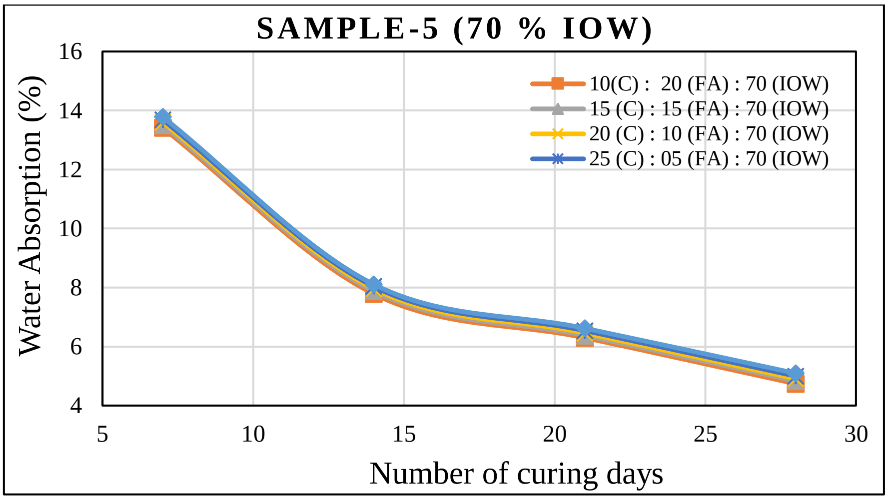

Fig. 26 Water absorption percentage vs. number of curing days

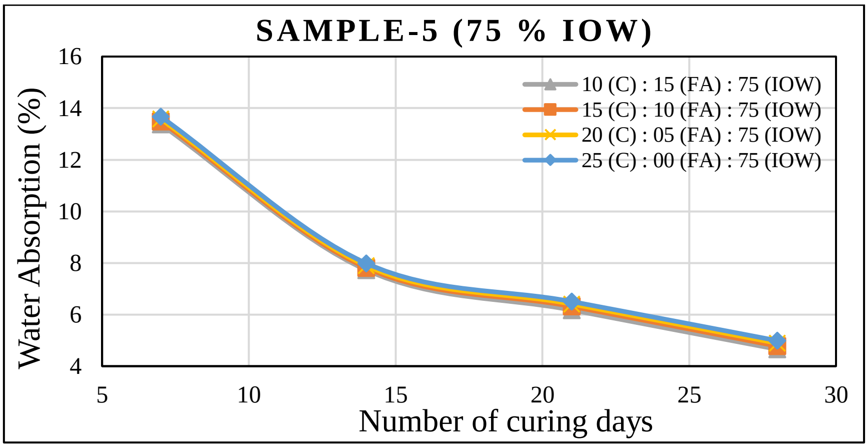

Fig. 27 Water absorption percentage vs. number of curing days

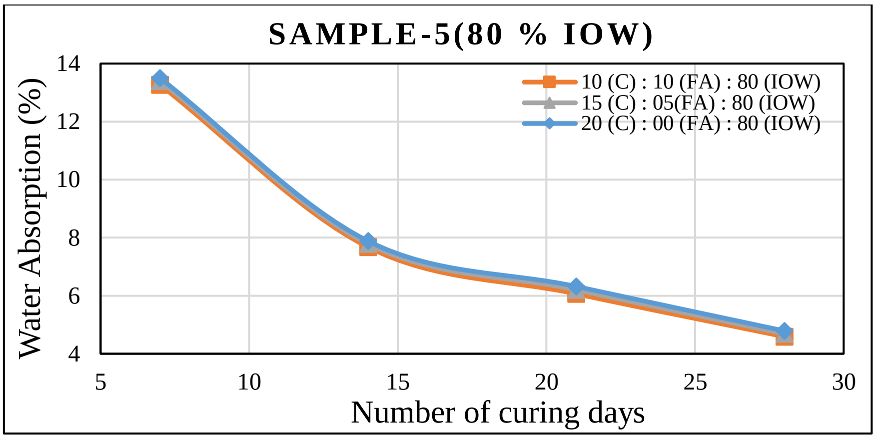

Fig. 28 Water absorption percentage vs. number of curing days

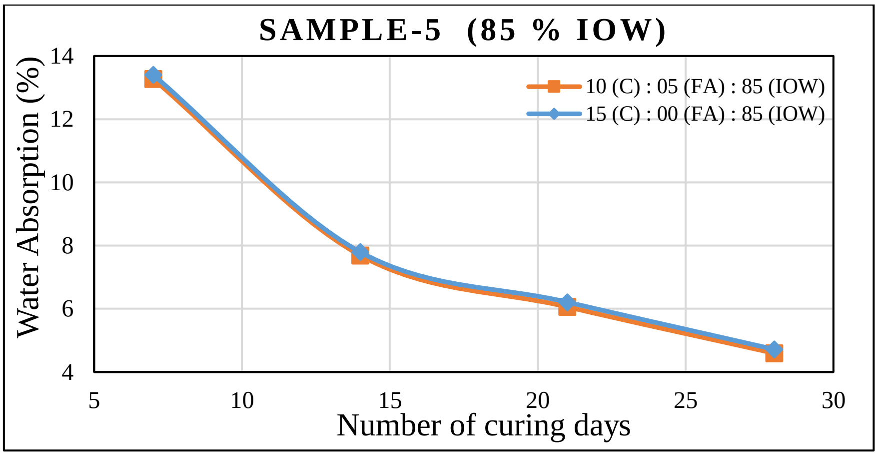

Fig. 29 Water absorption percentage vs. number of curing days

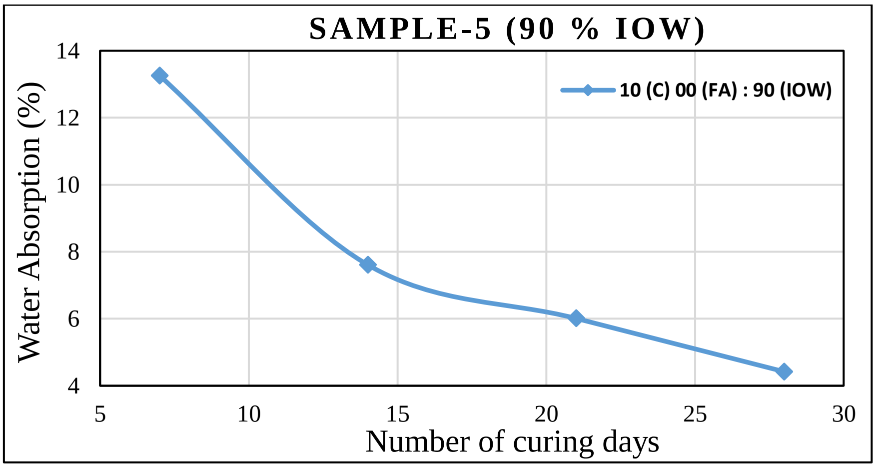

Fig. 30 Water absorption vs. number of curing days

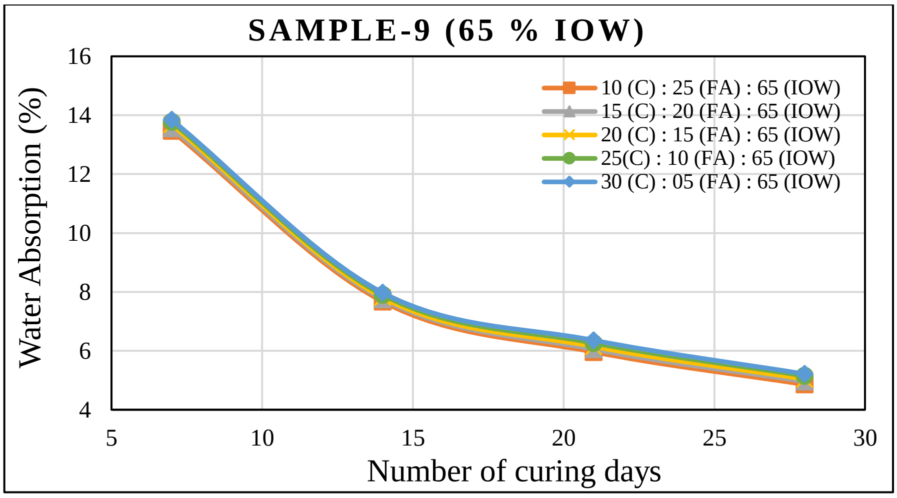

Fig. 31 Water absorption percentage vs. number of curing days

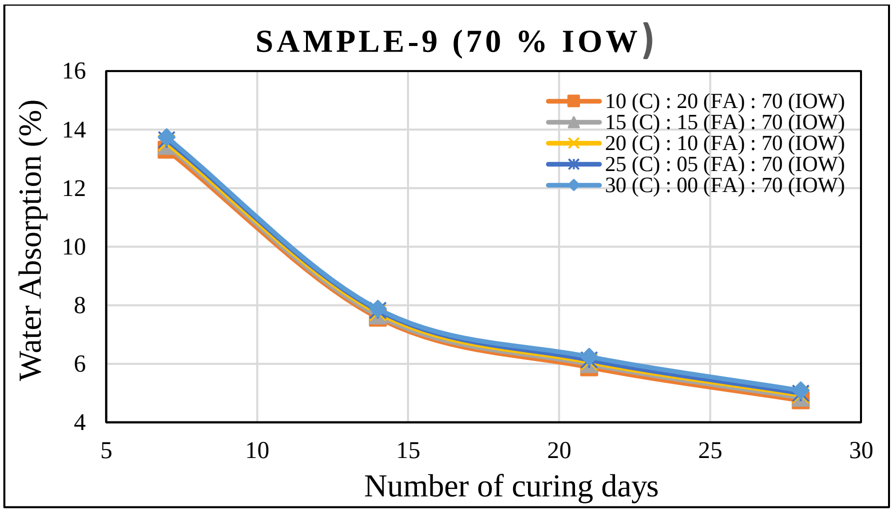

Fig. 32 Water absorption percentage vs. number of curing days

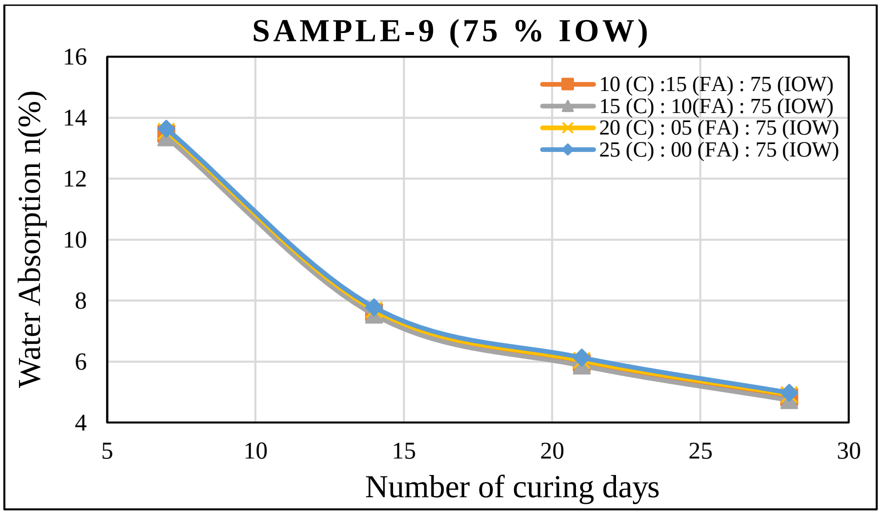

Fig. 33 Water absorption percentage vs. number of curing days

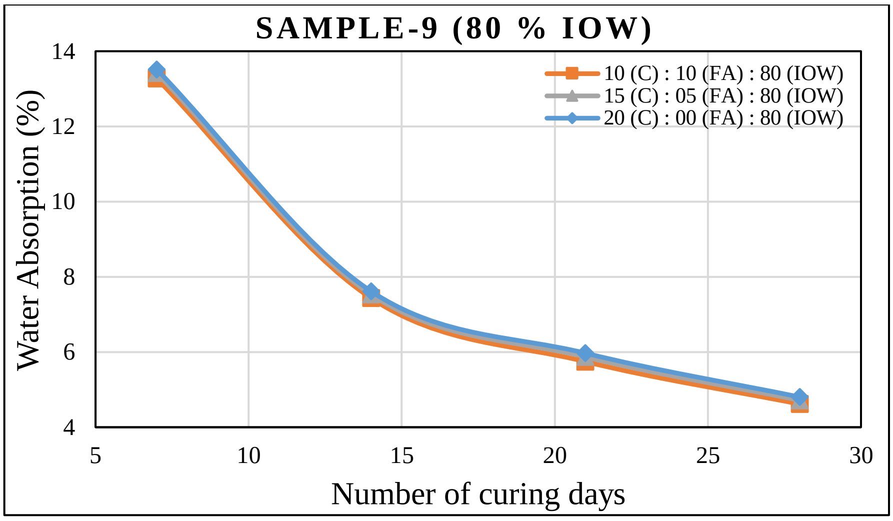

Fig. 34 Water absorption percentage vs. number of curing days

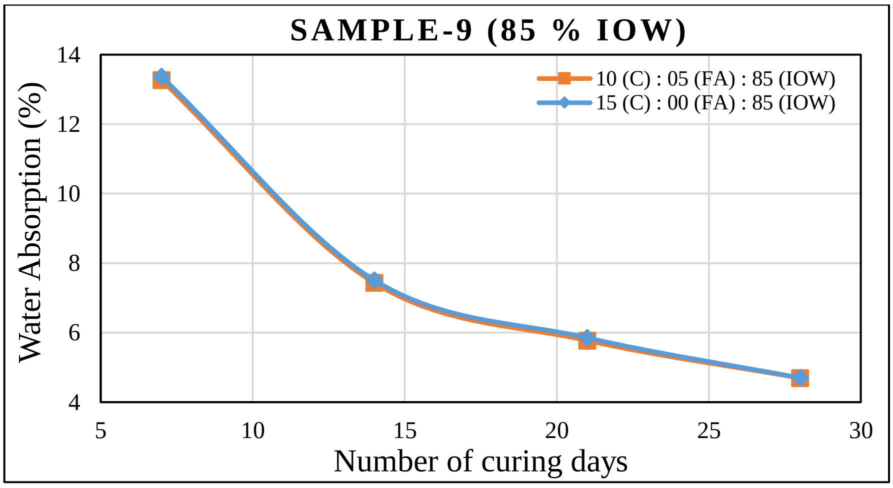

Fig. 35 Water absorption percentage vs. number of curing days

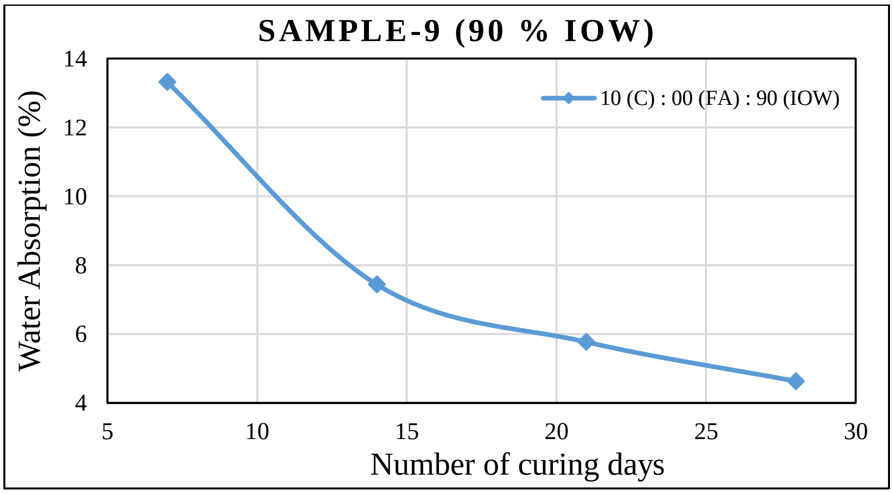

Fig. 36 Water absorption vs. number of curing days

ANNEXURE - V

Table 1 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.59	0.64	0.62	0.71	0.68	0.70	0.71	0.74	0.82	1.20	1.90	3.60	3.50	3.68	3.98	4.65
S2	0.61	0.62	0.69	0.76	0.66	0.73	0.76	0.77	0.85	1.00	2.20	3.55	3.47	3.65	4.20	4.60
S3	0.57	0.65	0.67	0.74	0.70	0.69	0.75	0.79	0.83	0.98	2.35	3.45	3.51	3.69	4.15	4.69
S4	0.62	0.60	0.71	0.77	0.69	0.75	0.73	0.75	0.79	1.25	2.40	3.52	3.48	3.88	4.25	4.70
S5	0.60	0.63	0.70	0.70	0.71	0.70	0.77	0.74	0.80	1.10	2.25	3.58	3.52	3.75	4.42	4.74
Average compressive strength (MPa)	**0.60**	**0.63**	**0.68**	**0.74**	**0.69**	**0.71**	**0.74**	**0.76**	**0.818**	**1.11**	**2.22**	**3.54**	**3.50**	**3.73**	**4.20**	**4.68**

Table 2 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.69	0.76	0.85	1.09	1.98	2.10	2.35	2.50	3.00	3.85	4.50	5.30	3.45	4.50	5.98	6.20
S2	0.70	0.82	0.90	1.10	2.05	2.15	2.40	2.65	3.20	3.60	4.55	5.25	3.60	4.45	6.10	6.17
S3	0.65	0.80	0.88	0.99	2.00	2.08	2.30	2.75	3.40	3.65	4.59	5.32	3.65	4.40	5.95	6.10
S4	0.59	0.79	0.94	1.05	1.95	2.17	2.25	2.55	3.35	3.76	4.60	5.29	3.50	4.35	5.97	6.19
S5	0.60	0.75	0.89	1.00	2.01	2.13	2.45	2.70	3.25	3.80	4.65	5.27	3.55	4.39	6.05	6.15
Average compressive strength (MPa)	**0.65**	**0.78**	**0.89**	**1.05**	**2.00**	**2.13**	**2.35**	**2.63**	**3.24**	**3.73**	**4.58**	**5.29**	**3.55**	**4.42**	**6.01**	**6.16**

Table 3 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.75	0.84	0.95	1.05	2.25	2.45	2.86	3.00	3.29	3.54	3.99	4.60	4.50	5.02	6.00	6.95
S2	0.71	0.89	1.00	1.01	2.19	2.36	2.78	2.98	3.22	3.56	4.02	4.65	4.55	5.00	5.98	6.99
S3	0.70	0.82	0.99	1.08	2.23	2.39	2.80	2.95	3.20	3.50	4.05	4.69	4.49	4.97	6.05	6.89
S4	0.73	0.90	0.92	1.10	2.20	2.43	2.84	2.90	3.26	3.53	3.98	4.55	4.53	4.99	6.03	7.00
S5	0.69	0.80	0.90	1.06	2.18	2.40	2.79	2.93	3.25	3.55	3.95	4.59	4.51	4.95	6.00	6.93
Average compressive strength (MPa)	**0.72**	**0.85**	**0.95**	**1.06**	**2.21**	**2.41**	**2.81**	**2.95**	**3.24**	**3.54**	**4.00**	**4.62**	**4.52**	**4.99**	**6.01**	**6.95**

Table 4 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-4, ANKAMNAL)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.68	0.70	0.79	0.99	1.98	2.02	2.25	2.88	2.10	2.45	3.20	3.88	3.61	4.29	4.50	5.15
S2	0.65	0.68	0.82	1.02	1.89	2.00	2.29	2.90	2.03	2.50	3.10	3.79	3.55	4.30	4.42	5.10
S3	0.55	0.75	0.80	0.92	2.00	2.05	2.20	2.95	2.08	2.40	3.13	3.85	3.50	4.35	4.49	5.13
S4	0.59	0.73	0.85	0.96	1.90	1.99	2.24	2.86	2.05	2.42	3.09	3.80	3.59	4.32	4.41	5.19
S5	0.60	0.70	0.80	0.90	1.95	1.96	2.27	2.97	2.00	2.39	3.11	3.76	3.60	4.30	4.45	5.17
Average compressive strength (MPa)	**0.61**	**0.71**	**0.81**	**0.96**	**1.94**	**2.00**	**2.25**	**2.91**	**2.05**	**2.43**	**3.13**	**3.82**	**3.57**	**4.31**	**4.45**	**5.15**

Table 5 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.71	0.79	0.83	0.97	1.97	2.10	2.35	2.85	2.10	2.68	3.50	3.98	3.47	3.70	3.98	4.25
S2	0.68	0.77	0.80	0.95	2.01	2.13	2.40	2.90	2.17	2.75	3.56	4.01	3.50	3.65	4.10	4.21
S3	0.73	0.75	0.89	0.99	1.95	2.15	2.38	2.88	2.15	2.70	3.49	4.10	3.49	3.75	3.99	4.29
S4	0.70	0.71	0.91	1.00	1.98	2.09	2.36	2.91	2.08	2.69	3.58	3.95	3.55	3.69	4.12	4.23
S5	0.69	0.73	0.85	1.04	2.00	2.10	2.42	2.87	2.19	2.72	3.54	4.05	3.52	3.72	4.15	4.27
Average compressive strength (MPa)	**0.70**	**0.75**	**0.86**	**0.99**	**1.98**	**2.11**	**2.38**	**2.88**	**2.14**	**2.71**	**3.53**	**4.02**	**3.51**	**3.70**	**4.07**	**4.25**

Table 6 Compressive strength of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				09:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Compressive Strength (MPa)															
S1	0.69	0.76	0.89	1.09	2.62	2.70	2.81	2.90	2.85	2.94	3.54	4.59	3.65	4.50	4.76	4.96
S2	0.65	0.74	0.85	1.07	2.61	2.75	2.79	2.88	2.90	2.88	3.45	4.57	3.69	4.59	4.79	5.15
S3	0.71	0.79	0.91	0.98	2.69	2.77	2.85	3.00	2.81	2.91	3.59	4.55	3.61	4.55	4.75	5.20
S4	0.67	0.82	0.90	0.95	2.63	2.69	2.83	2.95	2.87	2.93	3.51	4.50	3.72	4.60	4.72	5.00
S5	0.70	0.85	0.83	1.05	2.65	2.72	2.80	2.99	2.85	2.89	3.50	4.47	3.68	4.62	4.70	5.19
Average compressive strength (MPa)	**0.68**	**0.79**	**0.88**	**1.03**	**2.64**	**2.73**	**2.82**	**2.94**	**2.86**	**2.91**	**3.52**	**4.54**	**3.67**	**4.57**	**4.74**	**5.10**

Table 7 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-1, SK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	11.50	8.52	7.50	6.40	11.60	8.67	7.58	6.75	11.70	8.96	7.65	6.18	12.85	8.95	7.90	5.19
S2	11.52	8.45	7.45	6.45	11.62	8.70	7.55	6.80	11.78	9.00	7.69	6.15	12.79	8.99	7.85	5.15
S3	11.54	8.49	7.55	6.39	11.59	8.69	7.60	6.79	11.75	8.90	7.70	6.22	12.74	8.90	7.87	5.12
S4	11.57	8.42	7.52	6.52	11.64	8.65	7.62	6.77	11.69	8.97	7.77	6.19	12.80	8.92	7.99	5.20
S5	11.59	8.48	7.55	6.50	11.65	8.72	7.59	6.82	11.67	9.02	7.72	6.20	12.77	9.00	7.95	5.17
Average water absorption (%)	**11.53**	**8.47**	**7.51**	**6.44**	**11.61**	**8.68**	**7.59**	**6.78**	**11.73**	**8.96**	**7.70**	**6.19**	**12.80**	**8.94**	**7.90**	**5.17**

Table 8 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-2, KMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	11.35	7.02	4.05	4.20	11.55	7.20	4.19	4.35	11.99	7.45	5.00	4.50	12.98	8.90	6.50	4.60
S2	11.30	6.99	4.15	4.25	11.50	7.10	4.24	4.30	11.90	7.50	4.89	4.45	12.95	8.85	6.30	4.65
S3	11.28	7.00	4.09	4.29	11.45	7.07	4.2	4.32	11.95	7.47	4.95	4.49	12.90	8.82	6.35	4.69
S4	11.33	7.04	4.13	4.27	11.52	7.15	4.25	4.38	11.97	7.52	4.90	4.47	12.93	8.80	6.45	4.67
S5	11.37	7.06	4.17	4.30	11.49	7.18	4.28	4.35	11.93	7.49	5.10	4.43	12.96	8.92	6.55	4.63
Average water absorption (%)	**11.33**	**7.02**	**4.12**	**4.26**	**11.50**	**7.14**	**4.23**	**4.34**	**11.95**	**7.49**	**4.97**	**4.47**	**12.94**	**8.86**	**6.43**	**4.65**

Table 9 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-3, NK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	10.09	6.90	4.11	3.98	11.00	7.10	4.29	4.09	11.12	6.99	4.09	3.82	11.50	7.12	4.30	3.89
S2	10.06	6.86	4.00	3.93	11.05	7.13	4.33	4.01	11.17	6.96	4.05	3.85	11.45	7.00	4.35	3.90
S3	10.03	6.95	4.03	3.95	11.10	7.15	4.35	4.07	11.20	6.93	4.01	3.89	11.41	6.99	4.28	3.93
S4	10.10	6.88	4.05	3.99	11.07	7.09	4.30	3.99	11.19	7.00	4.07	3.91	11.37	7.10	4.39	3.95
S5	10.05	6.93	4.07	3.90	11.03	7.17	4.37	4.05	11.15	6.95	4.10	3.90	11.40	7.05	4.31	3.98
Average water absorption (%)	**10.07**	**6.90**	**4.05**	**3.95**	**11.05**	**7.13**	**4.33**	**4.04**	**11.17**	**6.97**	**4.06**	**3.87**	**11.43**	**7.05**	**4.33**	**3.93**

Table 10 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-4, ANKAMNAL)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	12.56	7.20	4.29	3.97	12.78	7.46	4.89	4.15	12.79	7.55	5.09	4.4	12.96	7.78	5.15	4.50
S2	12.49	7.15	4.25	3.89	12.80	7.43	4.90	4.10	12.69	7.56	5.01	4.35	12.85	7.75	5.10	4.39
S3	12.53	7.17	4.30	3.99	12.77	7.40	4.87	4.17	12.65	7.50	5.00	4.30	12.98	7.70	5.09	4.45
S4	12.50	7.11	4.22	3.92	12.83	7.47	4.91	4.12	12.67	7.53	4.99	4.39	12.84	7.67	5.12	4.40
S5	12.55	7.19	4.27	3.95	12.80	7.42	4.85	4.14	12.63	7.51	5.03	4.33	13.00	7.72	5.07	4.46
Average water absorption (%)	**12.53**	**7.16**	**4.27**	**3.94**	**12.80**	**7.44**	**4.88**	**4.14**	**12.69**	**7.53**	**5.02**	**4.35**	**12.93**	**7.72**	**5.11**	**4.44**

Table 11 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-5, JLK-YRD)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	12.97	6.88	5.79	4.25	13.09	7.50	5.98	4.50	13.29	7.68	6.19	4.60	13.35	7.81	6.34	4.90
S2	13.01	6.90	5.75	4.19	13.19	7.55	6.10	4.49	13.24	7.73	6.25	4.58	13.37	7.79	6.30	4.79
S3	12.99	6.78	5.77	4.21	13.15	7.45	6.05	4.41	13.30	7.69	6.21	4.63	13.30	7.75	6.32	4.88
S4	13.04	6.80	5.71	4.27	13.17	7.53	6.03	4.45	13.26	7.71	6.20	4.65	13.39	7.71	6.35	4.85
S5	13.00	6.92	5.69	4.20	13.10	7.51	6.09	4.47	13.22	7.70	6.23	4.59	13.31	7.77	6.37	4.81
Average water absorption (%)	**13.00**	**6.86**	**5.74**	**4.22**	**13.14**	**7.51**	**6.05**	**4.46**	**13.26**	**7.70**	**6.22**	**4.61**	**13.34**	**7.77**	**6.34**	**4.85**

Table 12 Water absorption percentage of bricks prepared with cement content of 7%, 8%, 9% and 12.5% (Sample-9, RMK)

Cement (C) : Fly ash (FA) : Iron ore waste (IOW)																
Proportion of material	07:28:65 (C:FA:IOW) (A)				08:27:65 (C:FA:IOW) (B)				9:26:65 (C:FA:IOW) (C)				12.5:22.5:65 (C:FA:IOW) (D)			
No. of days for curing bricks	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
Brick sample	Water Absorption (%)															
S1	12.74	6.79	5.05	4.05	12.97	6.95	5.24	4.35	13.15	7.29	5.45	4.67	13.46	7.56	5.79	4.05
S2	12.65	6.77	5.09	4.10	12.99	7.00	5.35	4.27	13.20	7.25	5.56	4.61	13.35	7.47	5.85	4.10
S3	12.69	6.75	5.15	4.08	13.01	6.80	5.20	4.30	13.17	7.30	5.65	4.69	13.39	7.50	5.89	4.07
S4	12.71	6.71	5.13	4.12	12.95	6.85	5.37	4.29	13.21	7.33	5.60	4.65	13.40	7.45	5.80	4.09
S5	12.70	6.70	5.10	4.09	13.03	6.90	5.18	4.25	13.24	7.35	5.59	4.70	13.42	7.54	5.83	4.03
Average water absorption (%)	**12.70**	**6.74**	**5.10**	**4.09**	**12.99**	**6.90**	**5.27**	**4.29**	**13.19**	**7.30**	**5.57**	**4.66**	**13.40**	**7.50**	**5.83**	**4.07**

PUBLICATIONS

Journals:

1. Shreekant R. L. Aruna M. & Harsha Vardhan, “Investigating the Utility of Iron Ore Waste in Preparing Non-fired Bricks”, Published online on 26th October 2016; Springer; Journal of the Institution of Engineers (India): Series D, DOI 10.1007/s40033-016-0129-5 (2016).

2. Shreekant R. L. Aruna M. & Harsha Vardhan, “Development of Value Added Product Using Iron Ore Waste for its Effective Utilisation”; International Journal of Advanced and Applied Sciences; December, 2015; Vol. 2(12); pp. 30-35.

3. Shreekant R. L. Aruna M. & Harsha Vardhan, “Utilisation of Mine Waste in the Construction Industry- A Critical Review”; International Journal of Earth Sciences and Engineering; February, 2016; Vol. 9(01); pp. 182-195.

4. Shreekant R. L. Aruna M. & Harsha Vardhan, “Utilisation of Iron Ore Waste in Brick Making for the Construction Industry”; International Journal of Earth Sciences and Engineering; April, 2016; Vol. 9(02); pp. 450-455.

5. Shreekant R. L. Aruna M. & Harsha Vardhan, “Impact of Al_2O_3, SiO_2 & Fe_2O_3 Present in Bricks Prepared Using Iron Ore Waste on its Compressive Strength”; Journal of the Institution of Engineers (India): Series E, submitted on 28th Nov. 2016; Paper ID-IEIE-D-16-00043. **(UNDER REVIEW)**

International Conference:

1. Shreekant R. L. Aruna M., Harsha Vardhan and Govinda Raj M., “Eco-Friendly Approach for Utilisation of Iron Ore Waste in Brick Manufacturing”; 8th International Conference on Envirotech, Cleantech and Greentech (ECG), 20-21 Dec. 2016, Dubai.

Paper communicated:

1. Shreekant R. L. Aruna M. & Harsha Vardhan, “Development of Mathematical Models for Prediction of Compressive Strength and Water Absorption of Bricks Prepared Using IOW, Cement and Fly Ash with Different Mix Ratio”; **Submitted** to Mining Engineers Journal on January 10, 2017.

BIO - DATA

NAME: SHREEKANT REVACHAND LAMANI

DATE OF BIRTH: 03-06-1971

ADDRESS FOR COMMUNICATION: SHREEKANT REVACHAND LAMANI
Dept. of Mining Engineering
NITK, SurathkaL, Srinivasnagar Post
PIN – 575 025, D.K., MANGALORE, KARNATAKA
Email: Shreekant.rathod@gmail.com
kant_adit2002@yahoo.co.in
skant@nitk.ac.in
Phone: (O) 0824-2473399; ®0824-2474399;
(M) 09481015719

ACADEMIC RECORD STARTING WITH GRADUATION:

Degree	Specialization	College / University / Institute	Year of Joining	Year of Leaving	Percentage	Class / Division / Grade
BCA	Computer Applications	IGNOU	2003	2005	63.58	I Class
MCA	Computer Applications	IGNOU	-	Dec. 2005	61.39	I Class
M.TECH	System Analysis &Computer Applications	NITK-Surathkal	2007	2010	7.53 CGPA	I Class

EMPLOYMENT:

Employer	Position held	Date of Joining	Date of Leaving	No. of years	Pay with Scale of pay, (RS)
NITK- Surathkal	Asst.Executive Engineer	08-12-95	---	20	15600-34800
Centum Electronics, Bangalore	Technician	05-06-94	06-12-95	1 Year 6 Months	2500/M
Bharath Electronics, Bangalore	Technician (Casual Employee)	01-05-92	31-03-94	1 Year 10 Months	1500/M
Bharath Electronics, Bangalore	Technical Apprentice	26-04-91	25-04-92	1 Year	1000/M

PROFESSIONAL TRAINING RECEIVED/EVENTS ATTENDED:

A total of around 20 training events attended in the areas of Staff Development, Software Engineering, Personality Development, Digital Equipment Maintenance, Information Security System and Statistical Tools for Research etc.

TRAINING PROGRAMMES CONDUCTED:

Conducted training program on Internet Usage and Visual Basic & its Applications.

PROFESSIONAL EXPERIENCE:

Organization	Nature of work
IGNOU STUDY CENTRE – NITK SURATHKAL	Counselor for MCA and BCA Courses, 2010-2015
	Subjects taught: 1) Operating System Concepts & Networking 2) Systems Analysis and Design 3) PC Software Skills 4) Intranet Administration 5) Problem Solving Techniques
	Projects Guided for MCA – 01, BCA - 02

PAPERS PUBLISHED: 04

PAPERS UNDER REVIEW: 01

PAPERS COMMUNICATED: 01

STRENGTH: Hard Working, Sincere & Honest

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