UTILIZATION OF IRON ORE WASTE AND TAILINGS IN CONCRETE PAVEMENTS

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

GAYANA B C

DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA,

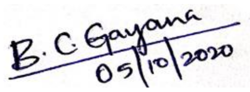
SURATHKAL, MANGALORE-575025

October, 2020

DECLARATION

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis entitled **"Utilization of iron ore waste and tailings in concrete pavements"** 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.



Gayana B.C
Reg. No.: 15503MN15F03
Department of Mining Engineering

Place: NITK-Surathkal

Date: 05.10.2020

CERTIFICATE

This is to certify that the Research Thesis entitled "**Utilization of Iron Ore Waste and Tailings in Concrete Pavements**" submitted by **Ms. Gayana B.C** (**Register Number:** 155003MN15F03) as the record of the research work carried out by her, is *accepted as the Research Thesis submission* in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy.

Dr. K Ram Chandar

Research Guide(s)

Date:

Chairman - DRPC

Date:

Dedicated to the

Almighty

ACKNOWLEDGEMENTS

The research work, which is presented in this dissertation, is more of teamwork and I would like to thank many who have contributed their time and energy for the study.

First and foremost, I am grateful to my advisor Dr. K Ram Chandar, Associate Professor & Head, Department of Mining Engineering, National Institute of Technology Karnataka, Surathkal (NITK) who consistently kept me motivated and instilled good thoughts not only for research but for life as well. His constant and enthusiastic support throughout is the root cause for the research work to see its end.

I am thankful to the Research Progress Assessment Committee (RPAC), Doctoral Research Programme Committee (DRPC) members Dr. Harsha Vardhan, Dept. of Mining Engineering and Dr. B.M Sunil, of Dept. of Civil Engineering for directing me to take the right path during the course of research. Their support and suggestions provided during various discussions have certainly helped in the betterment of this research work.

I am thankful to Dr. K Ram Chandar, Head, Department of Mining Engineering and Dr. Govindaraj and Dr. Aruna M, Former Heads of Department of Mining Engineering, NITK, Surathkal. I extend my gratitude to the authorities of NITK, Surathkal and staff of Department of Mining Engineering for their help provided during my research work.

I am grateful to Dr. K. U. M Rao, Director, Professor of Mining Engineering at IIT Kharagpur (Presently Director of NITK, Surathkal), Dr. Sudhakar Reddy, Professor of Civil Engineering at IIT, Kharagpur and Dr. Amarnath Reddy, Professor of Civil Engineering at IIT, Kharagpur for their guidance and support during my research interaction at IIT Kharagpur. Also, I would like to extend my gratitude to Dr. Krishna R. Reddy, Professor of Civil & Materials Engineering, University of Illinois, Chicago and Dr. M.E. Raghunandan, Senior Lecturer, School of Engineering, Monash University, Malaysia.

I am very thankful for the help rendered by Mr. Geethesh, Lab foreman and Mr. Ramanath, Lab instructor, Department of Civil Engineering who helped me enormously during sample preparation and testing.

I would like to thank my friends Dr. Kumar Doreti, Dr. Archana Singh, Dr. Vijay Kumar S, Bharath Kumar, Harish H, Harish Kumar N S, Tejas S, Sharath Kumar, Balaji Rao, Balraju, Sasi Kiran, Dr. Shreyasvi C and Dr. Suman Saha who have helped in various stages of the project at NITK, Surathkal, and made my stay feel comfortable. Also, I would like to thank Dr. Ramya Mullapadi, Assistant Professor, IIT Hyderabad and Dr. Anush K C, Assistant Professor, IIT Bhubaneshwar for their extensive support.

I would like to thank my guide Dr. Ram Chandar and his spouse Dr. Neelima and their entire family for being very supportive and encouraging all throughout my Ph.D. course.

I owe my deepest gratitude to my parents Mr. Chinnappa M and Mrs. Meena B.C and my in-laws Mr. Phanendra Rao K and Mrs. Indira K and my siblings Mr. Thejesh Kumar B.C. and Ms. Roopa Shree B.C. and my little niece Mrudani B.V for their support. Last but not the least, I owe my gratitude to my spouse Mr. K V Kanthi Kiran who has been very patient and supportive at all times. He has been strong and steady source of inspiration for me and there have been countless moments while pursuing my research that, without him, I feel I would have succumbed to defeat. I thank everyone from the bottom of my heart for the unconditional support and being a witness for every step of the way. I thank them for all the sacrifices they have gone through to give me the best of the best things in life.

Gayana B.C

ABSTRACT

ABSTRACT

With the augmenting infrastructure, the need for construction materials is increasing in various applications viz., buildings, bridges and pavements. The quantity of materials required for pavement construction is huge. At present scenario, in a few states within India, sand mining is banned due to which it is affecting the construction industry. So, many research works are being focussed on utilization of indusial waste in pavements. A systematic research study is taken up to utilize iron ore mine waste and iron ore tailings in concrete pavements.

The main objective of this research study is to evaluate the properties of concrete mixes with marginal materials derived from mine waste i.e., iron ore waste rock (WR) and iron ore tailings (IOT) as coarse and fine aggregates with suitable admixtures for M40 grade concrete based on requirement. The fresh and hardened properties of concrete determined were workability, compressive, splitting tensile and flexural strength. Rapid Chloride Permeability Test (RCPT) was conducted to determine its durability property.

Experimental investigations were carried out for three different material compositions. Firstly, two different mixes were considered, one set of concrete mixes with WR as coarse aggregates and other set of concrete mixes with IOT as fine aggregates were replaced partially by 10%, 20%, 30%, 40% and 50% for 3, 7 and 28 curing days with varying water-cement (w/c) for each composition by 0.35, 0.40 and 0.45. Around 162 cubes, 54 cylinders and 54 beams were casted for each mix composition and tested for their strength properties. Optimum strength was obtained at 40%, 30% and 20% replacement of WR in concrete and at 30%, 20% and 10% for IOT concrete for 28days cured specimens, for 0.35, 0.40 and 0.45 w/c. Concrete mix with IOT was workable with higher w/c compared to 0.35 and 0.40 w/c; this is due to the high specific gravity of IOT. In case of WR concrete, workability was found to satisfy the design criteria. Flexural strength observed for IOT and WR concrete mixes ranged between 4.50 to 5.10 MPa. Similar trend was observed in case of compressive and splitting tensile strength.

To enhance the strength properties of concrete mixes with WR and IOT replacement, alccofine was used as a binder replacement by 10%. Similar to the first case, two different mixes with WR and IOT as coarse and fine aggregates respectively in concrete were considered with 10% alccofine at 10%, 20%, 30%, 40% and 50% for 3, 7, 28 and 56 days curing. Water-cement (w/c) ratio varied for each composition by 0.35, 0.40 and 0.45. Around 216 cubes, 108 cylinders and 108 beams were casted for each mix composition and tested for their strength properties. Similar to WR and IOT concrete mixes, optimum strength obtained for 0.35, 0.40 and 0.45 w/c were at 50%, 40% and 30% replacement of WR-alccofine concrete and in case of IOT-alccofine concrete, optimum strength obtained were at 40%, 30% and 20% respectively. Here, compressive strength ranged between 55 to 75 MPa, splitting tensile strength ranged between 3.8 to 5.0 MPa and flexural strength ranged between 5.80 to 7.30 MPa for WR-alccofine and IOT-alccofine concrete mixes. In this case, density of concrete increased due to the high specific gravity of WR and IOT aggregates.

To reduce the density of WR-alccofine and IOT-alccofine concrete respectively and make it a light weight concrete, expanded perlite (EP) was added as partial replacement for fine aggregate by 0%, 2.5%, 5.0%, 7.5% and 10.0% for 3, 7, 28 and 56 days curing with varying w/c of 0.35, 0.40 and 0.45. In this case, control concrete mix with optimum percentage obtained from WR-alccofine and IOT-alccofine were considered for their respective w/c and later EP was replaced as fine aggregates for varying percentages. Based on the results obtained for EP-concrete, density reduced drastically and ranged between 2,600 Kg/m^3 to 2,300 Kg/m^3 making it a light weight concrete. Due to addition of EP in WR-IOT-alccofine concrete, strength also reduced due to its fineness and porous nature which absorbs water. However, the strength achieved from 5% EP concrete are still higher than the target strength requirement as per IS codes. Compressive strength varied between 58 MPa to 49 MPa. Similar results were obtained in the case of splitting tensile and flexural strength of concrete.

Based on all the above experimental investigations, it can be concluded that, for light weight concrete the optimum mix is with 5% replacement of EP concrete for all the w/c considered. For 0.35, 0.40 and 0.45 w/c the optimum percentage of mix consists

of WR-IOT-alccofine-EP of 50-40-10-5 percent and 40-30-10-5 percent and 30-20-10-5 respectively. Whereas, for high dense concrete applications, the optimum percentage of WR-alccofine for 0.35, 0.40 and 0.45 w/c is at 50%, 40% and 30% respectively. Similarly for IOT-alccofine concrete, the optimum percentage was found to be for 0.35, 0.40 and 0.45 w/c is at 40%, 30% and 20% respectively.

A statistically fitted multiple regression analysis was performed for all the mechanical properties to evaluate the significant level of concrete containing WR-alccofine, IOT-alccofine and EP-concrete mixes. These prediction models developed have high accuracy and low bias. The validation process presented that the equations can perform in a better way in predicting the WR-alccofine, IOT-alccofine and EP concrete properties.

Key words: Waste rock, iron ore tailings, alccofine, expanded perlite, strength properties, statistical analysis.

ACRONYMS

IOT	Iron Ore Tailings
WR	Waste Rock
EP	Expanded Perlite
GGBS	Ground Granulated Blast Furnace Slag
TDC	Thermal Dilation Coefficient
Mp	Mix Percentage
w/c	Water-Cement Ratio
Cd	Curing Days
RMSE	Root Mean Square Error
MAPE	Mean Absolute Percentage Error
HVFA-RAC	High-Volume Fly Ash- Recycled Aggregate Concrete
MS	Micro Silica
FA	Fly Ash
SCC	Self Compacting Concrete
RM	Red Mud
LSW	Limestone Waste
LWAs	Lightweight Aggregates
EPA	Expanded Perlite Aggregates
RA	Rubber Aggregates
RPA	Raw Perlite Aggregate
M.P	Mix Percentage
AAC	Autoclaved aerated concrete
CRRI	Central Road Research Institute
UHPC	Ultra High Performance Concrete
FESEM	Field Emission Scanning Electron Microscopy
RCA	Recycled Concrete Aggregates
CSA	Crushed Stone Aggregates
GRA	Gravel Aggregates
Hz	Hertz
COV	Coefficient of Variation

NA	Natural Aggregates
mm	Milli-meter
Kg	Kilo gram
kg/m^3	Kilo gram per cubic meter
mm^3	Cubic milli-meter
m^3	Cubic meter
% by wt.	Percentage by Weight
TM	Mine Tailings
MPa	Mega Pascal
GPa	Giga Pascal
CS	Compressive Strength
STS	Splitting Tensile Strength
FS	Flexural Strength
RCPT	Rapid Chloride Permeability Test
kN/s	Kilo Newton per Second
w.r.t	with respect to
viz.,	namely
i.e.,	in other words
M40	Mix of concrete with a characteristic compressive strength of 40 N/mm^2
M30	Mix of concrete with a characteristic compressive strength of 30 N/mm^2
M25	Mix of concrete with a characteristic compressive strength of 25 N/mm^2
N/mm^2	Newton per square milli-meter
IS	Indian Standards
V	Constant Voltage
WR1	Waste rock mix at 0.35 w/c
WR2	Waste rock mix at 0.40 w/c
WR3	Waste rock mix at 0.45 w/c
IOT1	Iron or tailings mix at 0.35 w/c
IOT2	Iron or tailings mix at 0.40 w/c

IOT3	Iron or tailings mix at 0.45 w/c
WR1A	Waste rock mix with alccofine at 0.35 w/c
WR2A	Waste rock mix with alccofine at 0.40 w/c
WR3A	Waste rock mix with alccofine at 0.45 w/c
IOT1A	Iron or tailings mix with alccofine at 0.35 w/c
IOT2A	Iron or tailings mix with alccofine at 0.40 w/c
IOT3A	Iron or tailings mix with alccofine at 0.45 w/c
EP1	Expanded perlite mix at 0.35 w/c
EP2	Expanded perlite mix at 0.40 w/c
EP3	Expanded perlite mix at 0.45 w/c
C_3S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_4AF	Tetracalcium Aluminoferrite
$Ca(OH)_2$	Calcium Hydroxide

MATHEMATICAL SYMBOLS

(+)	Addition
(-)	Subtraction
(/)	Division
(x)	Multiplication
>	Greater Than
<	Lesser Than
=	Equal To
( )	Round Bracket
[ ]	Square Bracket
Π	Pi
√	Square Root
%	Percentage
| |	Modulus
°C	Degree Celsius
ɑ	Alpha

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1

CHAPTER 1

1. INTRODUCTION

This chapter deals with the brief introduction about concrete, its sustainability, need for alternative materials along with research objectives and methodology.

1.1. General

Transportation is vital for economical, industrial, social and cultural development of any country. The inadequate transportation facilities retard the process of socioeconomic development of the country. The road network is the only mode of transportation, which gives maximum service to all and is the only mode which offers the maximum flexibility to travellers in selecting routes, direction, time and speed of travel (Morth 2012a). Road network alone serves the remote areas. The well-being of citizen, economic growth and status of a country is judged by how well organized and efficient the road network is. A wide variety and range of roads is in use all-round the globe. The terrain, topography, population, culture, the function and structural requirements are the factors that decide that type of road. Development of a country depends on the connectivity of various places with adequate road network. Roads are the major channels of transportation for carrying goods and passengers. They play a significant role in improving the socioeconomic standards of a region. They are important assets for any nation. In case of India, India is the second largest road network country in the world, with more than 46,99,024 km which includes 96,214 km of national highways and expressways, 1,47,800 km of state highways and 44,55,010 km of other roads (https://www.cia.gov/library/publications/resources/the-world-factbook/geos/in.html).

Roads are laid using different materials like gravel, sand, aggregates, bitumen, cement, etc. There has been a constant research to replace or substitute the materials with other materials for better pavement of roads, to reduce the cost, to increase the tyre life, etc. In the process, the waste produced from various sources can be an effective replacement, as the waste will be available at free of cost or with minimum price and on the other hand, handling and disposal of waste also minimizes at the source. One of the sources for such waste is the Mining Industry.

Mining Industry is a basic sector after agriculture. Waste generated from mining includes overburden waste, tailings and other processed waste. Management of mining waste is likely to be of some significance in many developing countries where recycling / extraction and processing of minerals have important economic values.

There are two methods of mining, one is open-cast and the other is underground mining. Open-cast mining involves removal of complete waste rock to expose the ore body or coal. The process of removing the waste bound to damage the natural ecosystem by producing various types of pollution like land degradation, air pollution, dust pollution, etc. The waste produced is generally dumped outside the mine in the form of overburden dumps. These dumps occupy a large amount of land, which loses its original value and generally gets degraded. Maintaining stability of such dumps is also a major issue for the mining industry (Sastry & Ram Chandar, 2013). Utilization of such waste rock is being investigated by various researchers for different purposes like building construction materials, pavements, back filling, etc. Hence, a partial replacement of the aggregates in concrete by waste rock produced from mines not only saves considerable money in the handling and maintenance of waste dumps but also reduces the cost of construction of roads. In addition, it also reduces the environmental problems at mine site.

The natural reserves or key minerals are to the tune of 82,000Mt such as iron ore, bauxite, dolomite, gypsum, limestone, mica, chromite, manganese, zinc, graphite, etc. India presents significant opportunities in mining and metal space. Production of such large quantity of iron ore also increases generation of large quantity of waste.

A systematic research work is taken up to study the utilization of iron ore mine waste and tailings as substitutes for coarse and fine aggregates in concrete pavements.

1.2. Objectives of Present Research Study

The main objectives of the research work are as follows:

(a) To study the physical, chemical properties and microstructure of iron ore overburden waste rock and tailings.

(b) To determine the effect of water-cement ratio for 0.35, 0.40 and 0.45 for the mechanical properties of concrete with partial replacement of coarse and fine aggregates with iron ore overburden waste rock and tailings respectively for varying curing days i.e., 3, 7, 28 and 56 days and add suitable additives to enhance the properties of concrete.

(c) To optimize the density and strength properties of final composition of concrete, by adding perlite as additive.

(d) To study the durability properties of iron ore overburden waste rock and tailings in concrete.

(e) To find economic feasibility for replacement of iron ore waste and tailings with conventional aggregates and sand in concrete for application in road construction.

1.3. Research Methodology

Following is the methodology followed for achieving the above objectives of the research and a schematic diagram of the same is shown in Fig. 1.1.

(a) Samples of iron ore waste and tailings were collected from iron ore mines based on the requirement from Hospet-Bellary region of Karnataka State, India.

(b) The physical properties of aggregates viz., iron ore waste and tailings are determined such as grain size distribution, density, moisture content, crushing strength, hardness, toughness, durability, shape factor, specific gravity and waster absorption as per IS standards as shown in Table 1.2.

(c) Mix design of concrete is done by selecting suitable ingredients of concrete and determining their relative proportion with the object of producing concrete of certain minimum strength and durability as economical as possible.

(d) The samples were casted for different mix proportions for aggregates replaced with iron ore waste and tailings

(e) Concrete samples were prepared and curing was done for 3, 7, 14, 28 and 56 days.

Table 1.1 Different tests for aggregates and their respective codes

Property of aggregate	**Type of Test**	**IS code**
Crushing strength	Crushing test	IS: 2386(Part 4)
Hardness	Los Angele's abrasion test	IS: 2386(Part 5)
Toughness	Aggregate impact test	IS: 2386(Part 4)
Durability	Soundness test	IS: 2386(Part 5)
Shape factor	Shape test	IS: 2386(Part 1)
Specific gravity and water absorption	Specific gravity test/ water absorption	IS: 2386(Part 3)

(f) Mechanical properties of the WR concrete samples are determined by experimental investigations such as workability, compressive strength, split-tensile strength, flexural strength, fatigue test as per IS codes for waste rock. The durability of the concrete mixes with IOT and WR samples are determined by Rapid Chloride Permeability Test (RCPT).

(g) After finding the optimum composition which gives highest strength, additives are added like perlite for that composition and optimum percentage is determined. Accordingly samples are prepared to test the strength properties.

(h) Cost analysis is done to assess the economic feasibility of replacing the iron ore waste and tailings with conventional aggregates in concrete pavement.

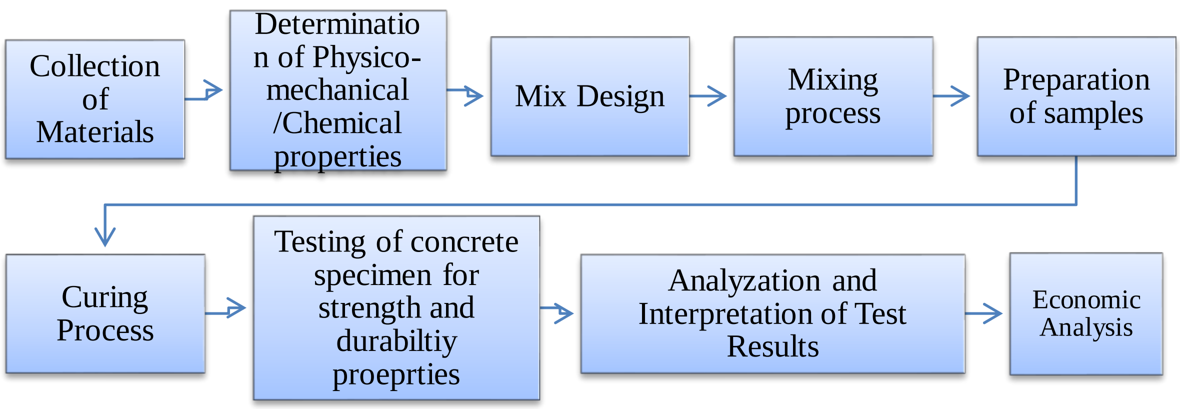


Fig. 1.1 Schematic representation of the methodology.

1.4. Organization of Thesis

CHAPTER 1

The background on the road network is given; brief note on mining and the waste generated, objectives and research methodology are presented in this chapter.

CHAPTER 2

A comprehensive literature review has been carried out regarding the studies carried out by previous researchers in the area of utilization of various marginal aggregates in concrete viz., iron ore tailings and waste, alccofine, GGBS, silica fume and perlite.

CHAPTER 3

Details of various materials used, basic properties of concrete ingredients and the design for M40 grade concrete are discussed in this chapter. The equipment used and procedure followed as per IS standards to determine the mechanical and durability properties of concrete are discussed. Laboratory studies with statistical analysis on mechanical properties and durability properties using iron ore mine waste and tailings and perlite in concrete are presented in this chapter.

CHAPTER 4

This chapter presents the detailed discussion on results and observations of the mechanical and durability properties of concrete mixes. Details of optimum and development of prediction models are discussed in this chapter.

CHAPTER 5

Conclusions drawn based on the investigations; recommendations and scope for the future study are presented in this chapter.

CHAPTER-2

CHAPTER 2

2. LITERATURE REVIEW

This chapter deals with a detailed literature study on concrete pavements, utilization of industrial waste including iron ore waste / tailings in concrete.

2.1 General

Concrete is one of the most basic and critical components for any type of construction and plays an important role in building the nation's infrastructure. Concrete is a composite material which is composed of coarse and fine aggregates embedded in a matrix and bound together by a binder, which fills the space or voids between the aggregates (Mindess et al. 2003). Basically, concrete is a mixture of binder, water, aggregates and additives. The binder generally used in concrete production is OPC, which is mainly responsible for the mechanical strength. Utilization of a few industrial wastes as binder material could result in higher strength compared to OPC concrete strength. One of the major construction projects includes road construction which develops the country's infrastructure. Road networks alone connect the remote areas to the urban areas. Most of the developing countries have focused on the development of road infrastructure in order to boost the economy, by proving proper road connectivity, which facilitate the safe and economic conveyance of goods between the source and the business hubs. Good road connectivity also serves the safe movement of passengers in the overland traffic. An extensive road network is one of the most important elements to promote the growth and development of any country. Hence a need to improve the quality of pavements by using various waste materials is in the scope of the study.
Types of roads/pavements and their effects are discussed below.

2.2 Pavements

Based on the design considerations, pavements are classified into two types i.e., flexible and rigid pavments. The difference between the two is based on the load distribution to the subgrade. Rigid pavement tend to distribute the load over a wide area of subgrade. The concrete slab on the top surface of the pavement itself supplies structural capacity in rigid pavement. In case of flexible pavements, load from the surface course is distributed to a smaller area towards the subgrade. Deflectoin of rigid and flexible pavements is shown in Fig. 2.1.

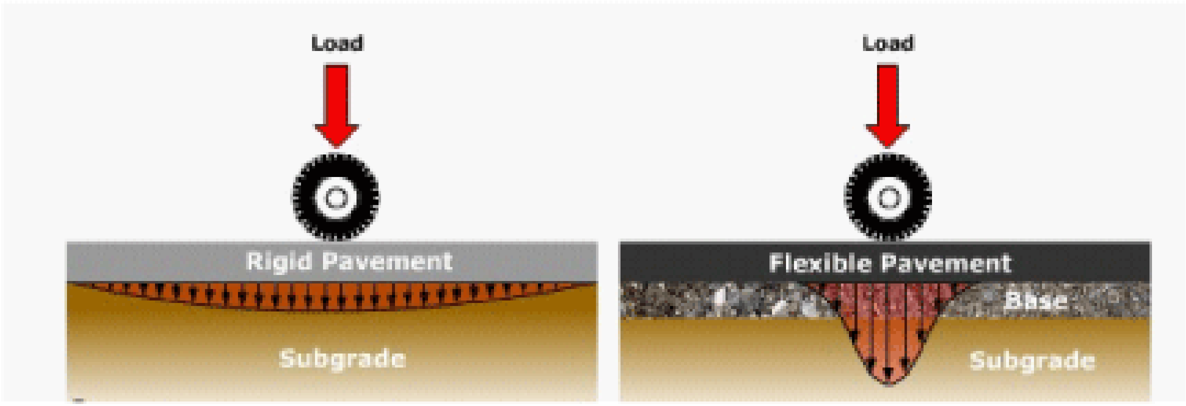


Fig. 2.1 Deflection of rigid and flexible pavements

2.3 Rigid Pavements

Concrete is the most versatile construction material in use all over the world. Concrete pavements are well known as rigid pavements. The roads built by concrete have more economical advantages in comparison with roads built by bituminous material. Road built by concrete has good sustainability. Many research works have been carried out on national highway which carried more axle loads (Chakravarthy and Kadiyali 1989). Concrete roads are preferred majorly in built in areas where there is high rainfall and curvy roads which carry greater traffic volume. .

Concrete roads have a number of advantages over bituminous roads. Concrete roads do not deflect under heavy loads like flexible pavements. Hence, vehicles require less energy (fuel requirement) while travelling on concrete roads. As per the trials carried out by Central Road Research Institute (CRRI), trucks consume 15-20% less fuel on concrete roads. Heavy trucks get upto 20% better mileage on concrete surfaces. The concrete roads require very little maintenance (CPAM 2012). Increased speed of vehicles on concrete road reduces congestion and traffic jams. The concrete roads are neither damaged by rain nor distorted by excessive heat.

Design life of bituminous roads may be 10 years with proper maintenance, which create a huge burden on natural resources. Concrete roads will have longer maintenance-free life which reduces the impact on nature. Concrete pavements reflect 33-50% lighter than asphalt surface. It offers a better visibility on rainy nights. Concrete provides better and durable skid resistance. Hence, they provide safety for the drivers. It is generally less slippery in wet weather than bituminous pavement (CPAM 2012). Concrete pavements promote utilization of industrial by-products like fly ash and slag (Naik 2008).

Design of concrete pavements is most significant parameter considered for the construction of concrete roads. Since the investment is higher and life of the roads is designed for three or four decade, the design of these roads has to be prominent. Improper design will lead to premature failure and requires huge cost for restoration technique. The design methodology has to take into account regarding change of environmental conditions as well as traffic growth. The optimal utilization of materials in the pavement structure demands for long term fatigue resistance at low cost and eco-friendly material.

The construction of modern highways with concrete pavements requires huge amount of natural resources such as stone and natural sand, which are depleting day by day. So, an alternative for such scarcity materials could be mine waste.

2.4 Mine Waste

Along with growth of mankind, the mining industry has also grown in parallel to supply raw materials for various purposes along with infrastructure development. There are two methods of mining, namely surface mining (Fig 2.2) and underground mining. In surface mining, overburden is removed and dumped aside, thus waste produced will be much higher than the coal ore extracted based on stripping ratio. Almost every coal as well as metal mining produces waste rock. The quantity of waste produced (shale and sandstone) in coal mines is in-terms of millions of cu. m per year. Sandstone is a highly porous rock and the strength is medium, so it may not be suitable for pavements. On the other hand, iron ore waste will have better strength, which can be used for pavements and it is also available in large quantity.

Fig. 2.2 A typical view of a surface mine in southern India

2.4.1 Iron ore waste and tailings

Iron ore is the key raw material used in the production of iron which represents 95% of all metal produced in a year (Ramanaidou and Wells 2014). Major application of iron is in structural engineering, automobile, machinery and other related application. Around two million metric ton of iron ore is produced each year. In India, around 10 million tons of iron ore is produced. Fig. 2.3 illustrates the production of iron from 2000 to 2018. The production of steel has been increasing with the demands.

The different types of mine waste are:

Overburden: In open pit mines, layers of material such as soil and rock are removed to extract ore deposits, referred as overburden. This overburden is deposited as tailing dumps on land to avoid heavy transportation cost.

Waste rock: Waste rock is a material that contains mineral in concentration considered too low to be extracted economically. Waste rock is suitable for earthworks on the site during mining operations and as aggregates for concrete works.

Tailings: Tailings are mineral waste products and finely ground rock which are subjected to processing. These tailings are converted to slurries in tailing pond. Some of these tailings are difficult to process due to its fine size, so this material is dried and can be utilized as alternate usage such as construction activity. Based on the type of tailings pond, the water can be drained so that the remaining waste can be dried.

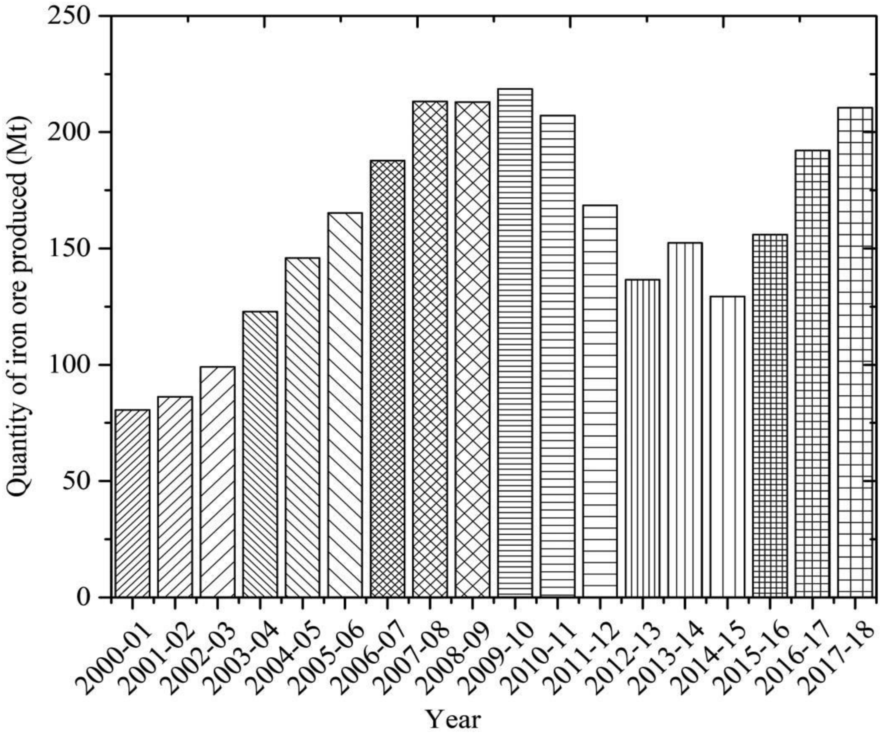


Fig. 2.3 Production of iron in India (Ministry of Mine, 2018.)

The main condition of mine waste utilization is that, materials should satisfy all the geotechnical criteria and is environmental friendly. A thorough characterization of mine waste is essential as it must not be a source of contamination. The value of utilization of mine waste can be enhanced on the basis of geotechnical properties and environmental constraints.

The suitable possibilities for utilization of mine wastes are in construction of tailing dams, roads and building, land filling and reclamation, designing embankment for reducing traffic sound, landscaping, stabilization in mine closure, neutralising acidic ground water and as fertilizer or supplement to enhance soil quality/fertility.

Depletion of non-renewable resources such as sand causes serious environmental threat. Excessive use of these materials is expensive because of non-availability and also due to transportation cost. Restrictions are made for obtaining these resources from river and a few states in India have banned sand mining. So, there is a scope for study of alternate material replacing non-renewable resources which are of low cost, high availability and environmentally friendly (Belhadj et al. 2014).

Various researchers have studied the utilization of iron ore waste rock and tailings in various aspects including replacement of sand, coarse aggregate or cement in concrete. A brief summary of the work carried by a few researchers are discussed below:

Waste produced from various stages of mining is to be disposed in an environmental friendly manner. It should not cause any land pollution, water pollution, air pollution, etc. The waste dump yards should be stable. In-order to avoid the environmental issues arising from the disposal of these wastes, it is better to use them for some other purpose.

Juwarkar et al. (2003) investigated the physico-chemical properties of the mine waste and suggested that, mixing of mine wastes with agriculture soils is threat to environment.

Mining industry has used iron ore tailings in the nearby industries to build roads and also for reclaiming the areas by backfilling the extraction zone (Skarzyńska 1995).

Previous research investigations related to various marginal materials as replacement for fine aggregates are discussed in the next section.

2.4.2 Replacement for fine aggregates

Iron ore tailings (IOT) include materials such as silica, iron oxides, alumina and other residual minerals. The material composition of IOT shows its potential use as an alternate material for construction activities (Huang et al. 2013; Da Silva et al. 2014; Yellishetty et al. 2008).

The comprehensive utilization of iron ore tailings (IOT) has major application in the field of land reclamation (Maiti et al. 2005), re-extraction of iron (Li et al. 2010; Sirkeci et al. 2006) and as one of the important material utilized in activities such production of infrastructure, backfilling and fertilizers materials (Zhu et al. 2011).

Wang and Wu (2000) and Zheng et al. (2010) reported the utilization of tailings in clinker and concrete respectively. Iron ore tailings (IOT) used as replacement of sand in concrete (Cai et al., 2009), as siliceous materials in ceramics (Das et al. 2000; Li and Li 2009) and autoclaved aerated concrete (Li et al. 2011). Use of IOTs in the construction activities provides no threat to environment and reduces the usage of sand obtained from river.

Ravi Kumar et al. (2012) studied the physiochemical properties of Interlocking Concrete Block Paver (ICBP) mixed with Iron Ore Tailings (IOT) as partial replacement of cement. For M25 grade concrete with varying the percentage of iron ore tailings (IOT), the mix resulted in an increase in compressive strength with IOT 5% to 15% and decrease in compression strength for IOT 15% to 25%.

Sun et al. (2011) investigated that, IOT used as cement-based gravel for road construction considering the properties such as strength, rigidity, water stability and resistance for frost. IOT cement-based gravel resulted in 7 days-age compressive strength higher than 2.5 MPa. So, it can be used for construction of heavy and low traffic duty pavement.

Research on replacement of sand with iron ore tailings to prepare Ultra High Performance Concrete (UPHC) was conducted (Zhao et al. 2014). When the replacement level was not more than 40% for 90 days standard cured specimen, mechanical behavior of tailings was comparable to that of control mix and the compressive strength decreased by less than 11% and flexural strength increased by 8% in comparison to control mix for specimen that were steam cured for 2 days. Fig 2.4 and Fig. 2.5 show the compressive and flexural strength of UHPC mixes under different curing regimes.

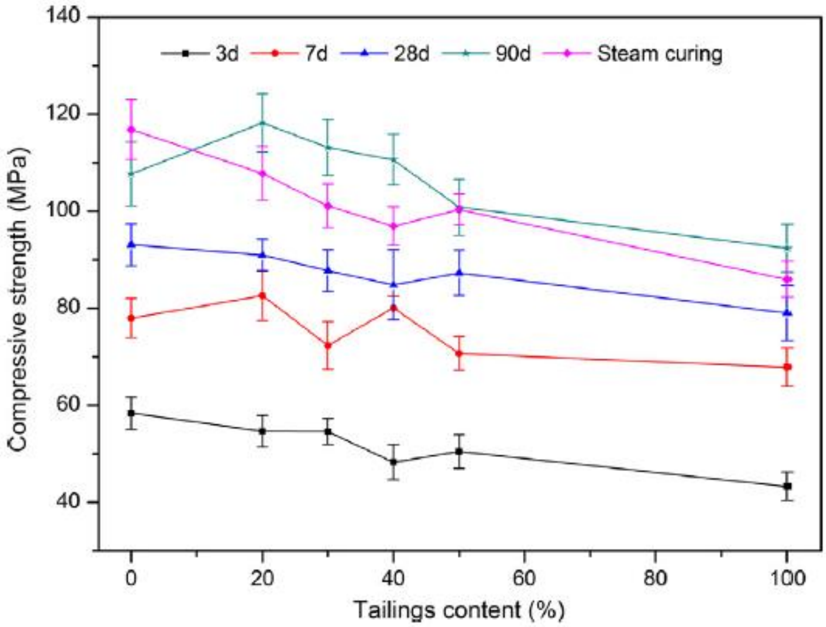


Fig. 2.4 Compressive strength results of Ultra High Performance Concrete mixes under different curing regimes (Zhao et al. 2014)

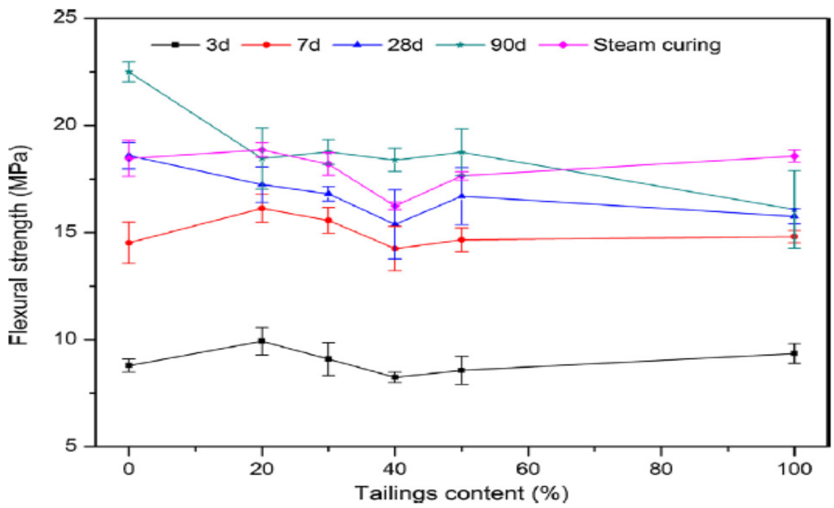


Fig. 2.5 Flexural strength results of Ultra High Performance Concrete mix under different curing regimes (Zhao et al. 2014)

IOT fly ash based geopolymer was investigated in laboratory scale, which are activated by sodium silicate and sodium hydroxide solutions after exposure to different thermal cycles at various heating temperatures (Duan et al. 2016). The results indicated that, decrease in compressive strength after 7 thermal cycles and loss in compressive strength increased as the cycle target temperature increased from 200º to 800º C. If the replacement with IOT is less than 30%, it improves the thermal resistance of geopolymer. Replacement of fly ash with 20% IOT leads to a reduction of porosity and micro cracking.

Experimental investigations on mechanical properties of IOT with cement were evaluated (Sunil et al. 2015). IOT with 35% replacement as fine aggregates and 20% replacement of cement with fly ash resulted in an increase in strength compared to the control mix concrete (Fig 2.6).

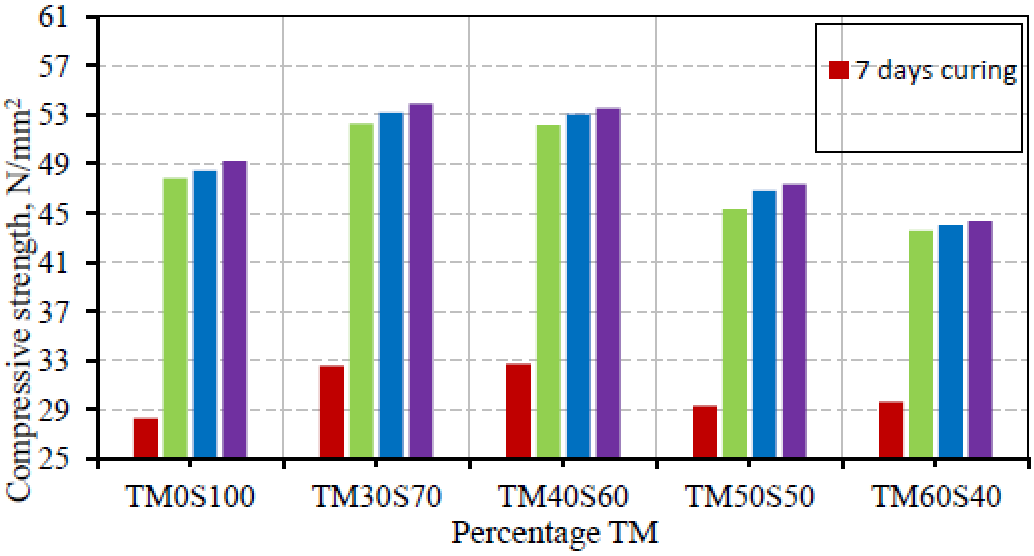


Fig. 2.6 Average compression strength of concrete at 7, 28, 56 and 90 days of curing with 35% Mine Tailings (TM) and varying percentage of Fly Ash (FA) (Sunil et al. 2015)

Recent trends in autoclaved aerated concrete (AAC) has increased the requirement of waste utilization during the production of AAC. A large number of researches was carried out on the utilization of waste material such as fly ash, air-cooled slag, coal bottom ash, efflorescence sand, copper tailings and carbide slag was studied for the possibility of using it as AAC production (Fan et al. 2014; Huang et al. 2012; Kurama et al. 2009; Mirza and Al-Noury 1986; Mostafa 2005); (Andre et al. 1999).

Further AAC production was carried out using coal residues and IOT. Bulk density and compressive strength prepared AAC was 609 kg/m^3 of 3.68 MPa respectively. This AAC mainly composed of 20% CGC, 40% iron ore tailings, 25% lime, 10% cement, 5% desulphurization gypsum and 0.06% aluminium powder (Wang et al. 2016).

Preparation of light weight tailings AAC block was recommended by (Ma et al. 2015). AAC block has bulk density of 490 and 525kg/m^3, compressive strength higher than 2.5 MPa with the composition consisting of cement, quicklime siliceous materials, gypsum and aluminium powder. Results for leaching test showed that AAC blocks with IOT were not a threat to environment.

IOT as a construction material in mortar preparation and coating was considered in the research study (Fontes et al. 2016). With IOT, mortar prepared was of three types i.e., conventional mortars, mortars with 100% replacement of fine aggregates by IOT and mortars replacing lime by IOT. Mortar characterization showed that IOT usage has increased the bulk density and also improved mechanical properties compared to the conventional mortar (Fig 2.7).

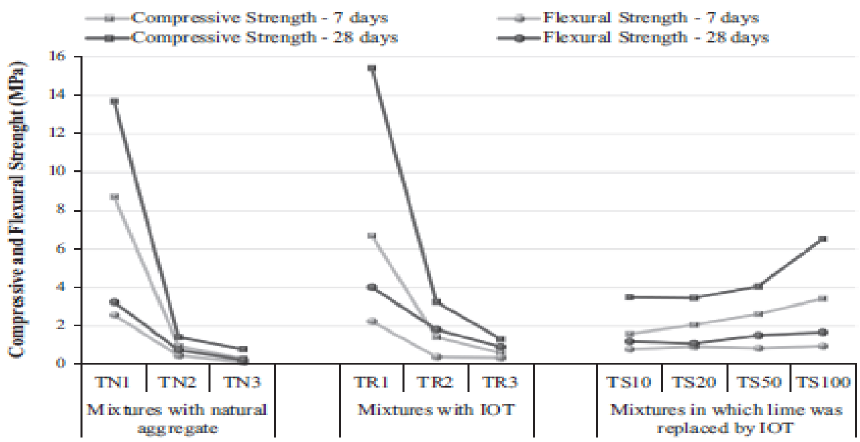


Fig. 2.7 Compressive strength and flexural strength of mortars with natural aggregates, Iron Ore Tailings and with lime replaced by Iron Ore Tailings (Fontes et al. 2016).

The properties of concrete with maximum IOT was investigated (Shettima et al. 2016). Fig 2.8 (a) & Fig 2.8 (b) shows the Field Emission Scanning Electron Microscopy (FESEM) at different magnification for concrete mixed IOT. SEM analysis showed that, presence of irregular and porous particle are dispersed. It was also found from the results that, the compressive strength of IOT concrete was higher and increase of 12.9% was observed for 25% replacement level there by reducing 25% sand replacement.

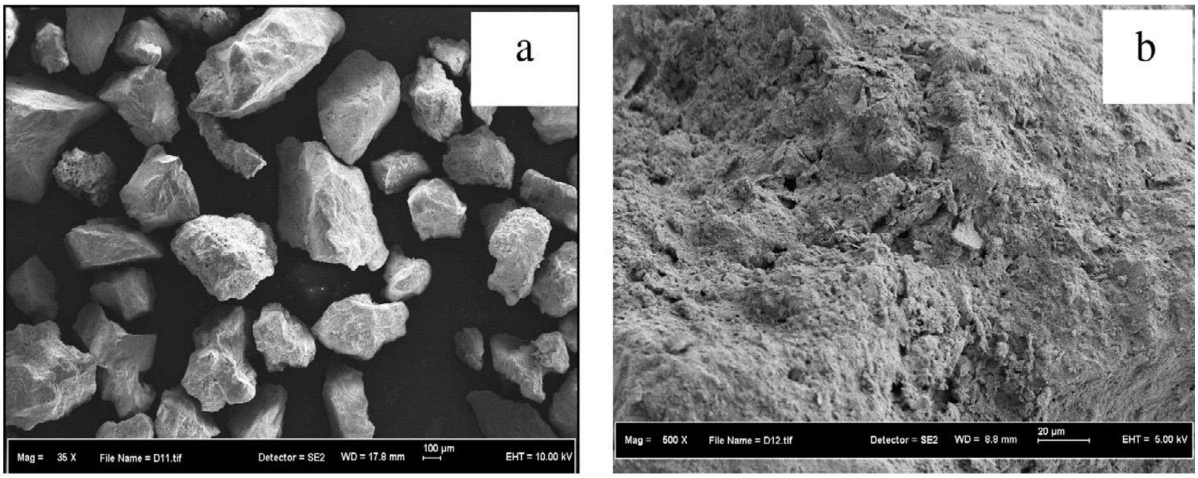


Fig. 2.8 Field Emission Scanning Electron Microscopy of IOT at (a) 25 lm and (b) 500 lm magnifications (Shettima et al. 2016).

2.4.3 Replacement for coarse aggregates

Iron ore waste from Goa was considered and experimental study was conducted (Yellishetty et al. 2008). In concrete mix, 40% of coarse aggregates were replaced with iron ore tailings (IOT) and concrete blocks were made for 28 days curing. It resulted in compressive strength of 21.93 MPa to that of granite aggregate of 19.91 MPa. Hence, increase in compressive strength was noticed with iron ore tailings (IOT) with respect to conventional coarse aggregate.

Three different aggregates were considered i.e., recycled material, crushed stone and gravel. From the investigations, it was found that, recycle based concretes has good compactibility and reduced particle breakage compared to other concretes (Park 2003) (Fig. 2.9).

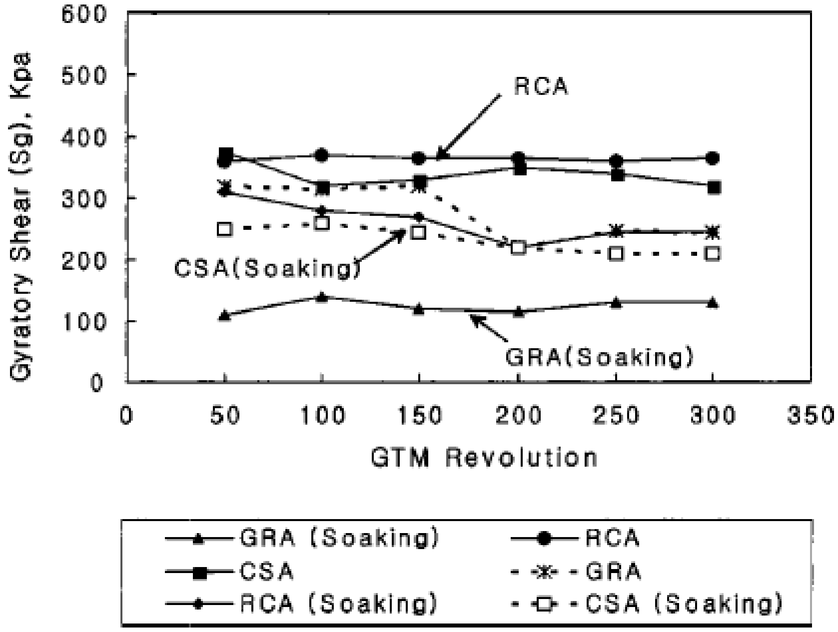


Fig. 2.9 Comparison of gyratory shear of Recycled Concrete Aggregates (RCA), Crushed Stone Aggregates (CSA) and Gravel Aggregates (GRA) (Park 2003).

Fatigue experiments were conducted on recycle based concrete and natural aggregates-based concrete of size 100mmx100mmx500mm and were tested under four-point loads of 10 Hz. It was found that, the recycle based concrete was having 50% fatigue life which was 8% and 7% lower than the natural aggregates-based concrete (Arora and Singh 2016). Fig. 2.10 and Fig. 2.11 shows the trend for comparison for shape factor and co-efficient of variation respectively for recycled aggregates and natural aggregates.

Waste materials like glass, plastics and demolished concrete is to be recycled for further study. The samples were prepared with 20% ground plastic and 20% crushed concrete and test for workability, unit weight, compressive strength, flexural strength and indirect tensile strength were conducted. The strength of samples was 25 MPa. It was concluded that glass, plastics and demolished concrete can be successfully used as a partial substitute for sand or coarse aggregates in concrete mixtures (Batayneh et al. 2007).

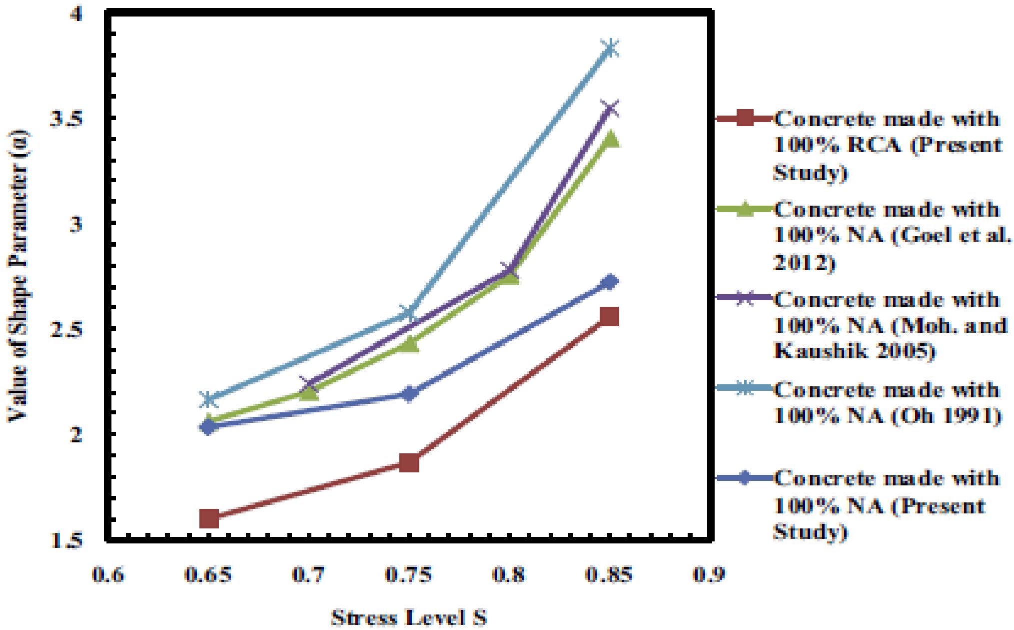


Fig. 2.10 Comparison of shape parameter ‘α’ of recycle based concrete and natural aggregates-based concrete (Arora and Singh 2016)

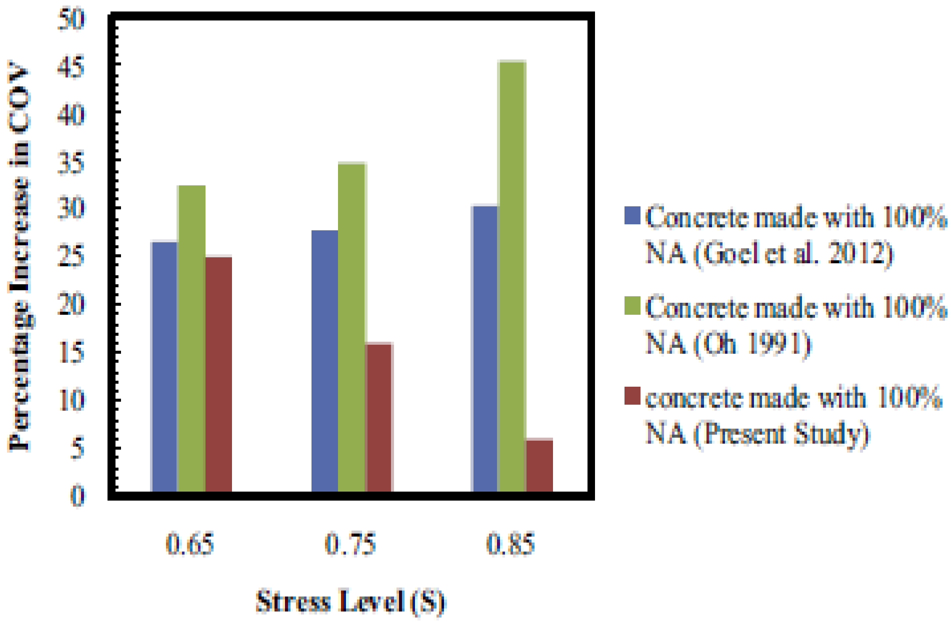


Fig. 2.11 Variation in coefficient of variation (COV) of concrete made with recycle based concrete and natural aggregates-based concrete (Arora and Singh 2016).

Experimental investigation for M30 grade concrete-based quartz sandstone was observed. The quartz stone varied from 0 to 100% in concrete. Testing was carried out to determine compressive strength, flexural strength, abrasive resistance, permeability and sorptivity in concrete samples. It was observed that concrete with 40% quartz stone achieved the required strength of 38.25 N/mm^2. At 100% replacement of quartz sandstone for 0.45 w/c ratio, the maximum abraded depth of 1.89mm (Fig 2.12) was obtained and permeability and sorptivity increased to a maximum of 0.46mm (Fig 2.13) (Kumar et al. 2016).

Coarse aggregates were replaced by ceramic tile waste material as aggregates in concrete. Ceramic tile materials were replaced by 20%, 25%, 35%, 50%, 65%, 75%, 80% and 100% in concrete. The compressive strength decreased by 4.3% and 5.6% and flexural strength decreased by 17.9% with 100% floor and wall tile replacement respectively compared with reference mix. The modulus of elasticity increased by 26.9% compared to 21.6 GPa measured in the reference concrete. Hence, results showed that, ceramics wastes can be used for preparation of concrete with reduced variation in mechanical properties.

Disposal of IOT causes major environmental threat such as contamination of soil, river and underground water (Dudka and Adriano 1997; Licskó et al. 1999; Moreno and Neretnieks 2006). So, the utilization of IOT in recovery (Das et al. 2002; Sirkeci et al. 2006), fired blocks (Yang et al. 2014), ceramsite (Das et al. 2000), concrete aggregate (Zhao et al. 2014) has becoming one of the important research topics in the last decade.

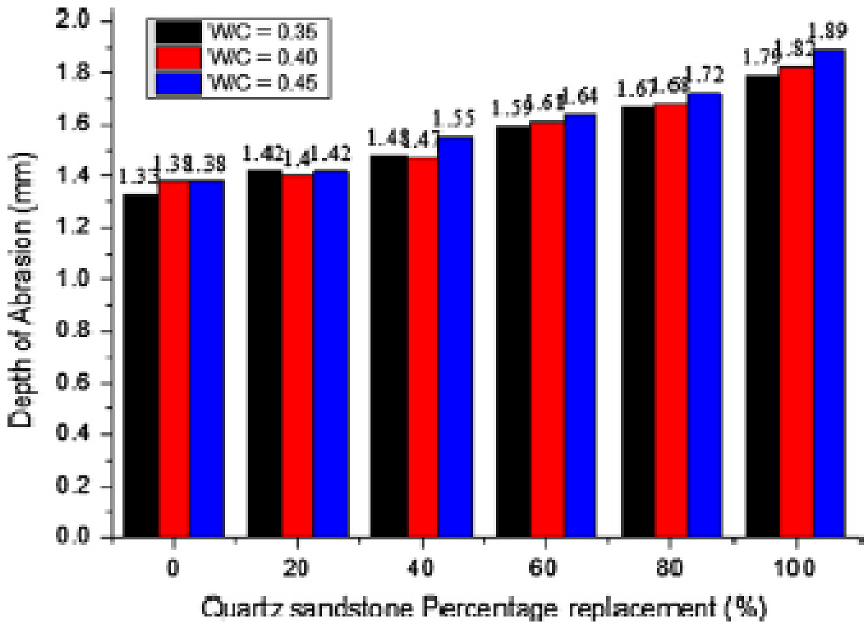


Fig. 2.12 Graphical representation of depth of wear vs. quartz percentage replacement (Kumar et al. 2016)

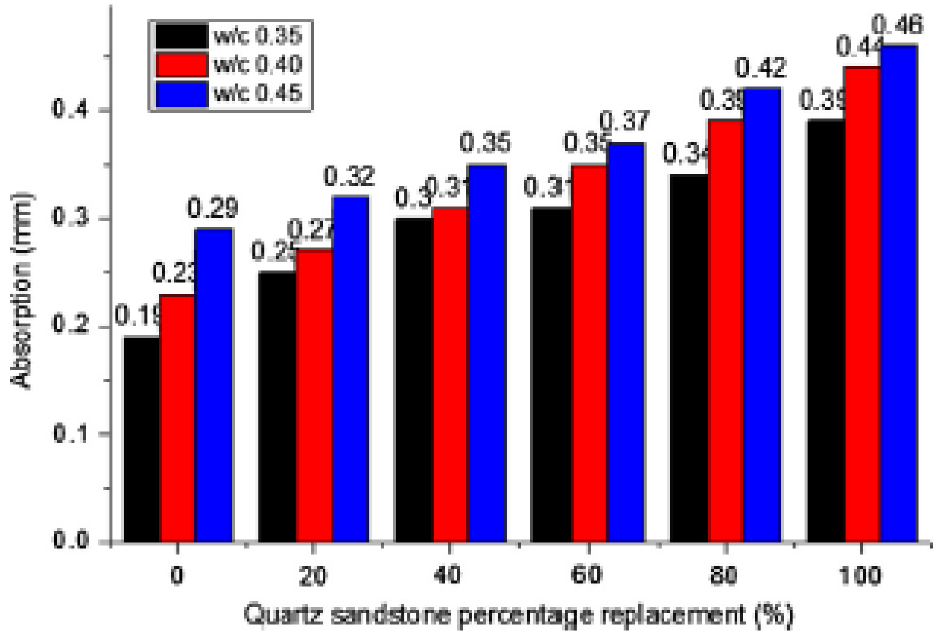


Fig. 2.13 Water absorption (Sorptivity) of concrete containing quartz sandstone aggregate (Kumar et al. 2016)

Few other waste materials used as a partial replacement of cement and aggregates in concrete by previous researchers are discussed below:

2.4.4 Other industrial waste considered for replacement for cement and fine aggregates

High-volume fly ash- recycled aggregate concrete (HVFA-RAC) with composition of micro silica (MS) as a partial replacement of cement with variation in 5, 10, 15% with 50% Fly ash (FA) and 35% recycled concrete aggregates (RCA) as partial replacement of cement in concrete manufacturing were investigated experimentally. It was concluded that HVFA-RAC has significant improvement in mechanical properties (Shaikh et al. 2015).

Strength aspects of Self Compacting Concrete (SCC) prepared by partial replacement of cementitious materials by Red Mud (RM) at 1%, 2%, 3% and 4% and in the same mix by partially replacing sand by Iron Ore Tailings (IOT) at 10%, 20%, 30% and 40%. The compressive strength and flexural strength achieved was found to be more than the conventional mix at 2% RM and 30% IOT (Shetty and Nayak 2014). Partial replacement of sand with laterite and sandstone respectively were investigated in laboratory scale, and found that, though there is not much improvement on strength properties of concrete yet these can be used as a replacement for sand (Chandar et al. 2016; Karra et al. 2016).

Limestone waste (LSW) with powdered marble was used in production of concrete. The replacement of sand with limestone waste at varying percentages of 25%, 50% and 75% in concrete mixes and 5%, 10% and 15% powdered marble were used in the concrete mix. The mechanical properties of fresh and hardened concrete with the effect of limestone as replacement for fine aggregates were investigated using compressive, indirect tensile strength, flexural strength, modulus of elasticity and permeability. The result shown that, the limestone waste as fine aggregate enhanced the slump test of the fresh concrete and unit weight concrete were not affected and the compressive strength increased by 12% for 28 days (Table 2.2). It was observed that the performance was good when the limestone waste as fine aggregate was used in presence of marble powder (Omar et al. 2012).

The usage of foundry sand and bottom ash wastes in production of concrete were determined. These samples prepared with variation of (0-60%) were tested for compression, split tensile and flexural strength and durability characteristics viz., rapid chloride penetration. It was found that the compression, splitting tensile and flexural strength samples was of 29-32 MPa, 1.80-2.46 MPa and 3.95-4.10 MPa respectively. It was also observed that these wastes can be used up to 30% in concrete (Siddique 2014).

Table 2.1 Result of compressive strength for specimens phase-1 (350 kg/m^3) and phase-2 (450 kg/ m^3) (Omar et al. 2012)

Mix symbol	**LSW (%)**	**M.P (%)**	**Compressive strength (MPa) for Phase 1 (350kg/m^3)**			**Compressive strength (MPa) for Phase 2 (450kg/m^3)**		
			7 days	**28 days**	**90 days**	**7 days**	**28 days**	**90 days**
N^*_{-350}	0.0	0.0	26.2	33.5	36.7	29.7	41.7	45.8
$N_{25\text{-}350}$	25		27.9	38.1	39.7	31.5	41.9	48.4
$N_{50\text{-}350}$	50		29.3	37.7	40.9	28.9	40.3	45.2
$N_{75\text{-}350}$	75		28.1	31.8	35.2	27.1	38.2	44.3
$N_{1\text{-}350}$	0.0	5	29.3	35.2	38.4	35.5	44.1	49.7
$N_{2\text{-}350}$		10	31.7	39.0	42.3	37.9	48.4	52.8
$N_{3\text{-}350}$		15	33.7	40.6	44.5	40.7	51.2	56
$N_{4\text{-}350}$	25	5	31.1	39.0	42.3	36.4	44.3	50.3
$N_{5\text{-}350}$		10	36.2	42.2	44.8	37.1	46.9	53
$N_{6\text{-}350}$		15	38.8	44.1	46.5	39.8	50.2	55.1
$N_{7\text{-}350}$	50	5	31.2	38.3	41.9	33.6	43.4	46.9
$N_{8\text{-}350}$		10	34.9	41.7	44.3	36.4	46.8	50.1
$N_{9\text{-}350}$		15	36.5	43.6	46.4	37.8	48.4	53.2
$N_{10\text{-}350}$	75	5	28.5	35.5	37.2	31.5	42.5	46.5
$N_{11\text{-}350}$		10	30.1	38.6	41.6	33.1	46.9	48.8
$N_{12\text{-}350}$		15	31.2	40.7	43.4	35	49.1	51.8

A brief introduction of admixture with the study made by previous researchers is discussed in the subsequent section.

2.4.5 Admixture

Admixtures are major material in concrete apart from of Portland cement, water and aggregate. Admixtures are added during mixing of concrete and it is considered to be cost effective with increasing properties of hardened concrete to ensure the quality of concrete during mixing, transporting, placing and curing. Some of the application of admixtures are in the production of Air-entraining, Water-reducing admixtures, Plasticizers, Accelerating admixtures, Retarding admixtures, Hydration-control admixtures, Corrosion inhibitors, Shrinkage reducers, Alkali-silica reactivity inhibitors, Coloring admixtures.

Some of the major factors which affect quality of admixture are cement composition, moisture content, mix time, slump and temperature of concrete. Some of the other factor such as concrete mixture-reducing water-cement ratio, adding additional cement, using a different type of cement or changing the aggregate and aggregate gradation was achieved during the admixture’s addition.

One such type of admixture is bonding admixture. Admixtures are water emulsions of organic materials which included rubber, polyvinyl chloride, polyvinyl acetate, acrylics, styrene butadiene copolymers and other polymers. This material when mixed with Portland cement with proportion varying from 5% to 20% increases strength. This varying percentage mainly depends on the properties of the concretes to be achieved(http://www.ce.memphis.edu/1101/notes/concrete/PCA_manual/Chap06.pdf)

One of the admixtures used in concrete to increase the workability and strength of concrete is alccofine. They are used as partial replacement of cement. Alccofine, expanded perlite and other admixtures are discussed in the next section. The recycled rubber produced and the research work reported by previous researchers regarding the feasibility and properties when used in concrete are discussed below.

2.4.5.1 Alccofine

The scope of research is towards green concrete and efforts are being made by the researches to find the suitability of marginal materials to replace cement and natural aggregates in concrete. Generally, the marginal materials used for replacement of cement are Granulated Blast Furnace Slag (GGBS), fly ash, silica, metakaoline, alccofine, etc. Alccofine is a by-product of slag and it is a micro fine material of particle size finer than other hydraulic materials like cement, fly ash, silica etc. Due to the optimized particle size distribution of alccofine, it enhances the performance of the fresh and hardened concrete.

Praveen et al, (2018) developed a geo-polymer concrete in laboratory scale using alccofine and fly ash as cementitious material. Based on the results obtained, the mechanical properties of geo-polymer concrete increased due to the addition of alccofine as it increases the densification process and enhances the mechanical properties of concrete. The optimum percentage at which the maximum compressive strength of 42 MPa obtained was at 10% replacement of cement with alccofine without elevated heat curing.

Narendra and Meena (2017) investigated the use of GGBS (0, 10, 20, 30 and 40%) as cementitious material in M30 grade concrete and then considering the optimum GGBS content constant, and by varying alccofine (8, 10, 12 and 14%) as cementitious material to study the performance of alccofine, the strength parameters resulted in reduction of strength with addition of alccofine.

Saxena et al, (2018) conducted an experimental study using pond fly ash with alccofine in geo-polymer mortar. Based on the results obtained, the strength increased along with its durability properties with addition on alccofine as a cement replacement.

2.4.5.2 Perlite

Perlite is a siliceous volcanic rock, which increases its volume with the increase in temperature. The world reserves of perlite are estimated at 700 Mt (https://en.wikipedia.org/wiki/Perlite). The volume increases to 4–20 times the original volume when the temperature is above 870°C (Chandra & Berntsson 2002).

The increase in volume results in low density improvement in high porous nature and water absorption. The various application of perlite is shown in Table 2.4. The expanded perlite is cost effective compared to the material such as exfoliated vermiculite, expanded clay or shale, pumice, mineral wool.

Experimental investigation was conducted with the used of perlite in concrete (Sengul et al. 2011). It was found that there was reduction in thermal conductivity, compressive strength and modulus of elasticity of the samples and also there was increase in water absorption and sorptivity. From the results it was clear that this concrete with 20% expanded perlite can be utilized as insulation concretes.

Table 2.2 Various applications of perlite along with their percentage of usage (Chandra & Berntsson 2002).

Estimated perlite consumption in U.S. by application	
Percentage	**Use**
53	Building construction products
14	Horticultural aggregate
14	Fillers
8	Filter aid
11	Other

Concrete made with the materials such containing silica fume (SF), superplasticizer (SP) and air-entrained admixtures with a constant water–cement ratio and normal aggregates replaced by lightweight aggregates (LWAs) including pumice (PA), expanded perlite (EPA) and rubber aggregates (RA) at different volume fractions of

10%, 20%, 30%, 40% and 50%. i.e., reductions at 28-day were 39.80%, 63.33%, 80.69%, 84.29% and 90.58%, and 35.46%, 54.89%, 74.80%, 80.90% and 81.66% for 10%, 20%, 30%, 40% and 50% EPA and PA, respectively and reduction by 18.91%, 41.35%, 63.28%, 81.65% and 91.26% were observed when 10%, 20%, 30%, 40% and 50% of the normal aggregate was replaced by an equivalent volume of RA, respectively. It resulted in improved insulation characteristics of the composite concretes. Furthermore, it was found that the reduction in thermal conductivity and diffusivity of the produced samples reached to 82% and 74% respectively (Fig 2.14) (Oktay et al. 2015b).

Concrete produced with the raw perlite aggregate (RPA) and different proportion of hooked steel, wavy steel and polypropylene fibers were studied (Gül et al. 2007). It was found that the increase in the steel fiber ratio have increased mixtures, unit weight, compressive strength, splitting-tensile strength and flexural strength to 4%, 11%, 143% and 227% respectively (Fig 2.15). The increase in the steel fiber ratio leads to a consistent increase in both strength and toughness up to a fiber content of 1.75%.

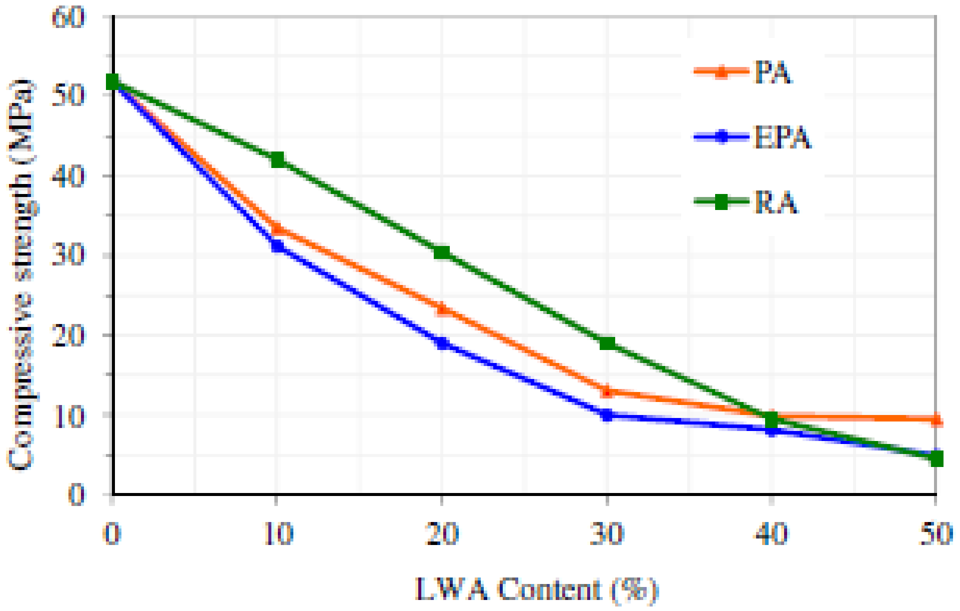


Fig. 2.14 Effect of Expanding Perlite Aggregates (EPA), Pumice Aggregates (PA) and Rubber Aggregates (RA) content on the thermal conductivity (Oktay et al. 2015a)

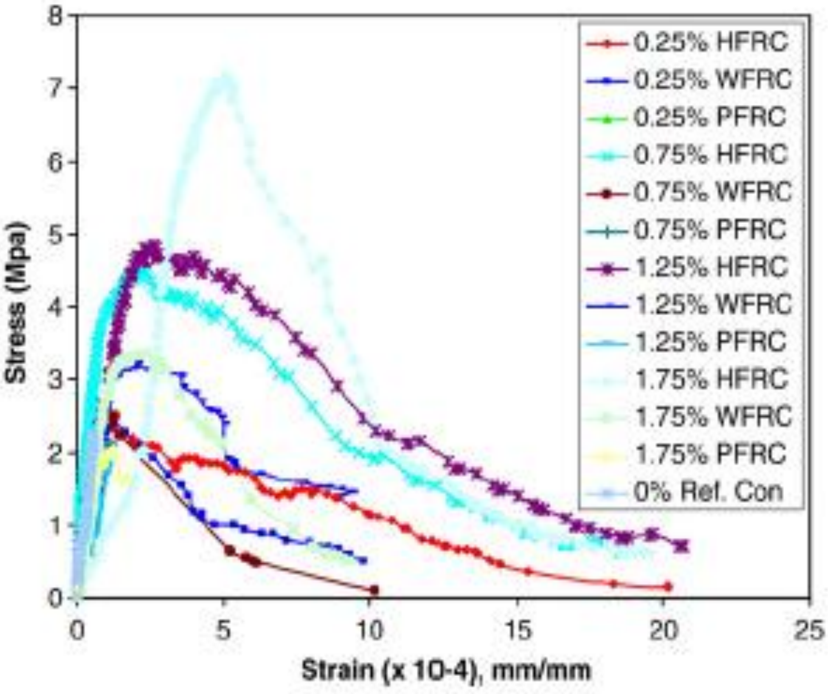


Fig. 2.15 Flexural strength vs. strain for fiber reinforced concretes (Gül et al. 2007)

2.4.5.3 Other admixtures

Various other admixtures were used to prevent early cracking of slabs, thermal behavior etc., of concrete.

A comparative study on the calcium chloride-based accelerator and a calcium nitrate-based accelerator in concrete mixtures on the early age cracking potential of concrete repair slabs were made (Meagher et al. 2015). From result, it could be concluded that the concrete was of more shrinkage, higher restraint stresses and higher strength for the calcium nitrate-based accelerator mixture. The simulation results from HIPERPAV software showed that the calcium nitrate-based accelerator mixture has lower cracking risk.

Thermal behaviour of cement matrix with the addition of 40% mineral admixtures within a well-sealed plastic cylinder which prevents the drying shrinkage was considered (Liwu and Min 2006). There was a decrease in liberation of heat and increase in shrinkage with the addition of fly ash, coal gangue and blast furnace slag.

Due to the presence of mineral admixtures the thermal dilation coefficient (TDC) of cement paste changes drastically with the hydration time.

The efficiency of reusing waste plastic in the production of concrete and replacement of sand in concrete with recycled waste by 0%, 10%, 15% and 20% were determined (Ismail and Al-hashmi 2008). The laboratory tests were performed with curing ages of 3, 7, 14 and 28 days to determine the slump, fresh and dry density and compressive strength and it resulted in the decrease of compressive strength with reference to the control mix (Fig 2.16). For the concrete mixture made of 20% waste plastic, flexural strength decreased by 30.5% with reference to the control mix (Fig 2.17). Therefore the results proved the arrest of the propagation of micro-cracks by introduction of waste plastic of fabriform shapes to concrete mixtures.

Addition of tailings from the concentration of iron ore for the production of red ceramics within 5% is highly feasible as an additive. The addition of iron ore concentration tailings to the ceramic mass resulted in an increase in its flexural strength by 30%, decrease in the density, increase in the porosity and decrease in the water absorption. The results were found desirable to the ceramic industry (Da Silva et al. 2014).

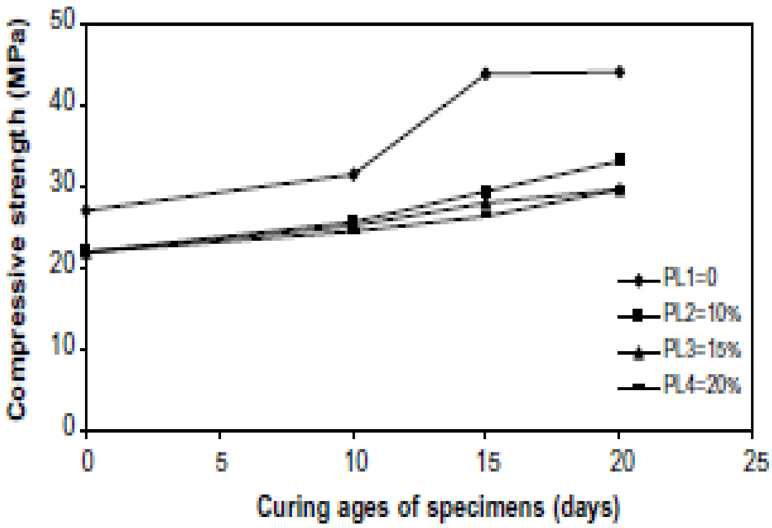


Fig. 2.16 Compressive strength with waste plastic (Ismail and Al-hashmi 2008)

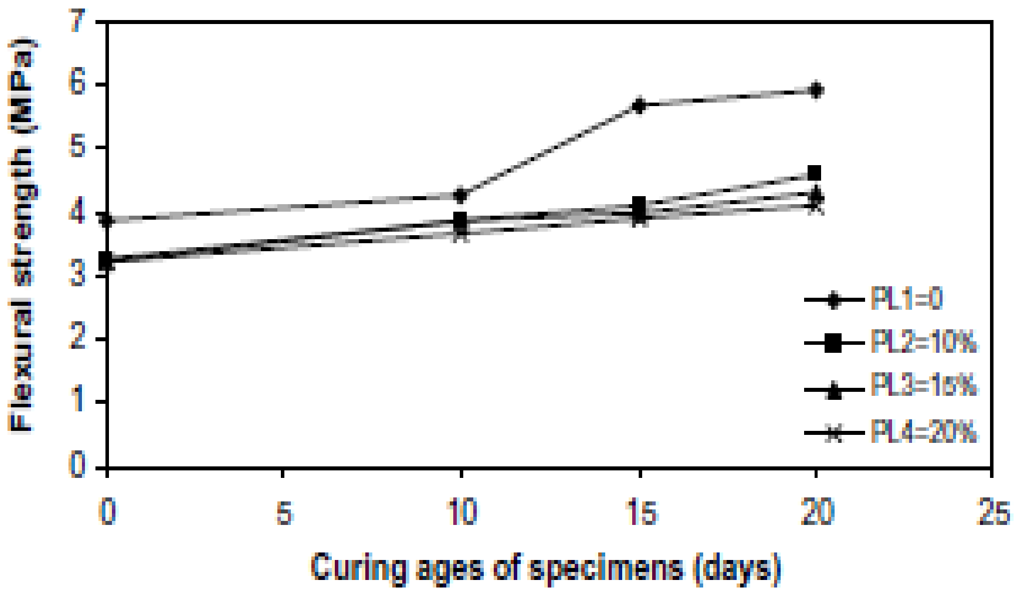


Fig. 2.17 Flexural strength with waste plastic (Ismail and Al-hashmi 2008).

2.4.6 Summary

This literature is compiled based on a thorough review of previous researchers work on utilization of mine waste along with some industrial waste in concrete as replacement for aggregates. The researchers have focused on utilization of different types of mine waste for replacement for specific applications. Other materials like glass waste, plastic waste and rubber waste were also tried for replacement of fine and coarse aggregates under different conditions. However, the studies on utilization of mine waste in concrete; combination of the iron ore mine waste rock and tailings has not been completely explored as aggregates replacement in concrete pavements. Hence, the utilization of these waste materials as partial replacement of fine and coarse aggregates in concrete can be done and its durability and mechanical properties can be determined in the application of concrete pavements by laboratory experimental investigations viz., compression, flexural and fatigue testing. Use of iron ore waste and tailings in concrete may improve strength, but density also increases. So, in order to reduce the density some additives like perlite can be used.

CHAPTER-3

CHAPTER 3

3. EXPERIMENTAL INVESTIGATIONS

3.1 Introduction

Materials used in the present research study and their properties are discussed in this chapter. The mix design for M40 grade, specimen preparation and details of the procedure adopted to determine the mechanical properties of concrete viz., compressive strength, splitting tensile strength, flexural strength and durability properties are discussed in this chapter. Statistical analysis carried out to predict the models for the parameters and to validate the experimental results, also given in this chapter.

Two types of iron ore mine waste materials were considered in the present study i.e., Iron Ore Waste Rock (WR) and Iron Ore Tailings (IOT) as replacement of coarse and fine aggregates in concrete respectively, along with alccofine as cement replacement. Preliminary tests were carried out to determine the physical and chemical properties of the materials. The chemical composition of the marginal materials was determined using X-ray Florescence (XRF).

3.2 Materials and Methods

The primary objective while collecting a sample for laboratory analysis is that its composition should be representative of the conditions that exists in the field. The procedure involves different sampling methods and here random sampling method was adopted. Accordingly, waste rock (WR) and iron ore tailings (IOT) samples were collected from Hospet- Bellary region of Karnataka state, India (Fig. 3.1 & 3.2).

Fig. 3.1 View of iron ore mine while waste rock samples were collected

Fig. 3.2 Collection of iron ore tailings (IOT) from tailings pond

The materials used and their properties are discussed in the following sections:

3.2.1 Cement

Ordinary Portland Cement (OPC) of grade 53 conforming to IS 12269:2013 was used for the laboratory investigations. The required tests for assessing the properties of cement were carried out according to IS 4031. The test results are shown in Table 3.1.

Table 3.1 Physical properties of cement

Sl. No.	Properties	Values obtained	Requirement as per IS 12269:2013	Remarks
1	Specific Gravity	3.15	----	The cement satisfies the requirement for 53 grade OPC stipulated by IS 12269:2013. Tests are conducted as per guidelines of IS 4031.
2	Standard Consistency (%)	29	----	
3	Fineness (m^2/kg)	300	Should not be less than 225	
4	Initial Setting Time (minutes)	60	Should not be less than 30	
5	Final Setting Time (minutes)	450	Should not be more than 600	
6	Soundness (By Le Chatelier Mould) (mm)	2	Should not exceed 10	

3.2.2 Coarse aggregates

Two types of coarse aggregates are used in the present study, locally available crushed granite and mine waste rock (WR).

a) Crushed granite

Crushed granite aggregates of maximum size of 20 mm (20mm to 4.75mm) conforming to IS 2386 (Part III, IV): 1963 were used. The aggregates were composed of a mixture of rounded and angular aggregates. The various properties of aggregates were determined as per IS 2386 (Part III, IV): 1963 and the specifications are checked as per IS 383: 1970 requirements. The physical properties of coarse aggregates are shown in Table 3.2 and Table 3.3, it gives the sieve analysis results conducted on coarse aggregates.

Table 3.2 Physical properties of crushed granite

Sl. No	Property		Value
1	Specific Gravity		2.8
2	Bulk Density (kg/m^3)	Loose	1370
		Compacted	1670
3	Moisture Content (%)		Nil
4	Water Absorption (%)		0.5

Table 3.3 Sieve analysis of crushed granite (Sample Weight 5.0 Kg)

IS Sieve Size (mm)	Weight Retained (kg)	% Weight Retained	Cumulative % Weight Retained	% Passing	IS 383:1970 Requirement (percentage passing for graded aggregate of nominal size 20mm)
40	0.00	0.0	0.0	100	100
20	0.23	4.6	4.6	95.4	95-100
10	3.41	68.2	72.8	27.2	25-55
4.75	1.33	26.6	99.4	0.6	0-10

Fineness modulus = 6.76

b) Iron Ore Waste rock (WR)

Iron ore waste rock (WR) was collected from an iron ore mine in Hospet, Bellary district of Karnataka state, India. Sampling was done as per IS 2386 (Part III, IV): 1963. The mine waste rock collected and packed in different bags with sample identification number for transportation. The samples were transported to the laboratory and tested for different properties. As there was not much variation among the properties of different samples, it was considered as a single type of rock. The average values of physical properties of the waste rock are given in Table 3.4. The sieve analysis results of waste rock are given in Table 3.5. The WR aggregates were tested for strength, toughness, hardness, shape test and water absorption. The values obtained are within the permissible limits as per IS code given in Table 3.6.

Table 3.4 Physical properties of waste rock (WR) as coarse aggregates

Sl. No	Property		Value
1	Specific Gravity		2.84
2	Bulk Density (kg/m^3)	Loose	1354
		Compacted	1658
3	Moisture Content (%)		NIL
4	Water Absorption (%)		0.45

Table 3.5 Sieve analysis of waste rock as coarse aggregates (Sample Weight 5.0 kg)

IS Sieve Size (mm)	Weight Retained (kg)	% Weight Retained	Cumulative % Weight Retained	% Passing	IS 383:1970 Requirement (percentage passing for graded aggregate of nominal size 20mm)
40	0	0.00	0.00	100.00	100
20	0.24	4.72	4.70	95.30	95-100
10	3.42	68.74	73.10	26.90	25-55
4.75	1.32	26.53	99.50	0.50	0-10

Fineness modulus = 6.77

Table 3.6 Aggregate tests for waste rock (WR) as coarse aggregates

Test	Property	IS code	Limit	Values obtained for waste rock
Aggregate Impact Test (%)	Toughness	IS: 2386 (Part 4)	30	7.69
Los Angele's Abrasion Test (%)	Hardness	IS: 2386 (Part 5)	40	12.80
Crushing Test (%)	Crushing Strength	IS: 2386 (Part 4)	35	30.76
Elongation Test (%)	Shape test	IS: 2386 (Part 1)	30	11.35
Flakiness Test (%)	Shape test	IS: 2386 (Part 1)	35	20.40
Soundness Test (Magnesium Sulphate) (%)	Durability	IS: 2386 (Part 5)	18	0.60

3.2.3 Fine aggregates

Two types of fine aggregates were used in the present study namely river sand and iron ore tailing (IOT). The physical properties, sieve analysis results and grading curve are discussed below.

a) River sand (Fine aggregates)

Locally available river sand conforming to zone II of Table 4 in IS 383:1970, passing through 4.75 mm sieve was used. The sand was free from organic matter and silt. The properties of sand such as fineness modulus and specific gravity were determined as per IS 2386-1963 (Part I). The physical properties of sand are shown in Table 3.7, sieve analysis report is given in Table 3.8 and the grading curve is shown in Fig. 3.3. Since the fineness modulus of river sand is 2.51, the sand can be considered as fine sand, as the range of fineness modulus to be considered as fine according to IS 383 is 2.2~2.6.

Table 3.7 Physical properties of river sand

Sl. No	Property		Value
1	Specific Gravity		2.70
2	Bulk Density (kg/m^3)	Loose	1440
		Compacted	1700
3	Moisture Content (%)		Nil
4	Water Absorption (%)		1

Table 3.8 Sieve analysis of river sand (Weight of sample = 1kg)

IS Sieve (mm)	Weight Retained (gm)	% Weight Retained	Cumulative % Weight Retained	% Weight Passing	IS 383:1970 Requirement For Grading Zone II
10	----	----	----	----	100
4.75	0	0.0	0	100	90-100
2.36	27	2.7	2.7	97.3	75-100
1.18	180	18.0	20.7	79.3	55-90
0.60	250	25.0	45.7	54.3	35-59
0.30	381	38.1	83.8	16.2	8-30
0.15	146	14.6	98.4	1.6	0-10

b) Iron ore tailings (IOTs)

Iron Ore Tailings (IOTs) were collected from Hospet, Bellary district of Karnataka State. Random sampling was done according to IS 2430:1986. The physical properties of IOTs were determined in laboratory and the details are presented in Table 3.9. The sieve analysis report of IOT is given in Table 3.10 and Figure 3.4 shows the grading curve.

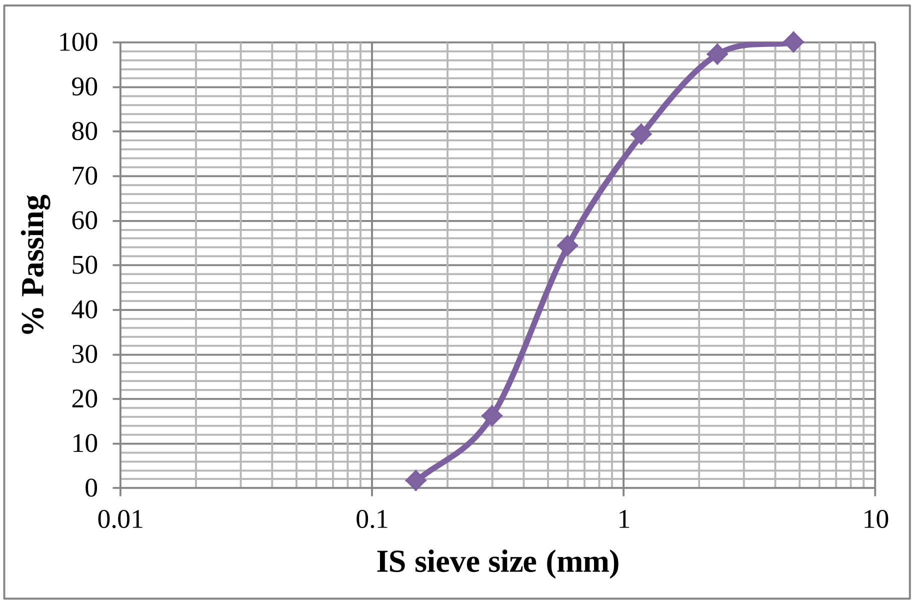


Fig. 3.3 Grading curve of river sand (Fine aggregates)

Fineness modulus = 2.51

c) Iron ore tailings (IOTs)

Iron Ore Tailings (IOTs) was collected from Hospet, Bellary district of Karnataka State. Random sampling was done according to IS 2430:1986. The physical properties of IOTs were determined in laboratory and the details are presented in Table 3.9. The sieve analysis report of IOT is given in Table 3.10 and Figure 3.4 shows the grading curve.

Table 3.9 Physical properties of Iron Ore Tailings (IOT)

Sl. No	Property		Value
1	Specific Gravity		3.31
2	Bulk Density (kg/m^3)	Loose	1684
		Compacted	1816
3	Moisture Content (%)		3.9
4	Water Absorption (%)		2.29

Table 3.10 Sieve analysis report of Iron Ore Tailings (IOT) (Weight of sample = 1000 gram)

IS Sieve (mm)	Weight Retained (gm)	% Weight Retained	Cumulative % Weight Retained	% Weight Passing	IS 383:1970 Requirement For Grading Zone II
10	----	----	----	----	100
4.75	7.40	0.74	0.74	99.26	90-100
2.36	26.40	2.64	3.38	96.62	75-100
1.18	206.00	20.60	23.98	76.02	55-90
0.60	330.00	33.00	56.98	43.02	35-59
0.30	240.00	24.00	80.98	19.02	8-30
0.15	175.00	17.50	98.48	1.52	0-10

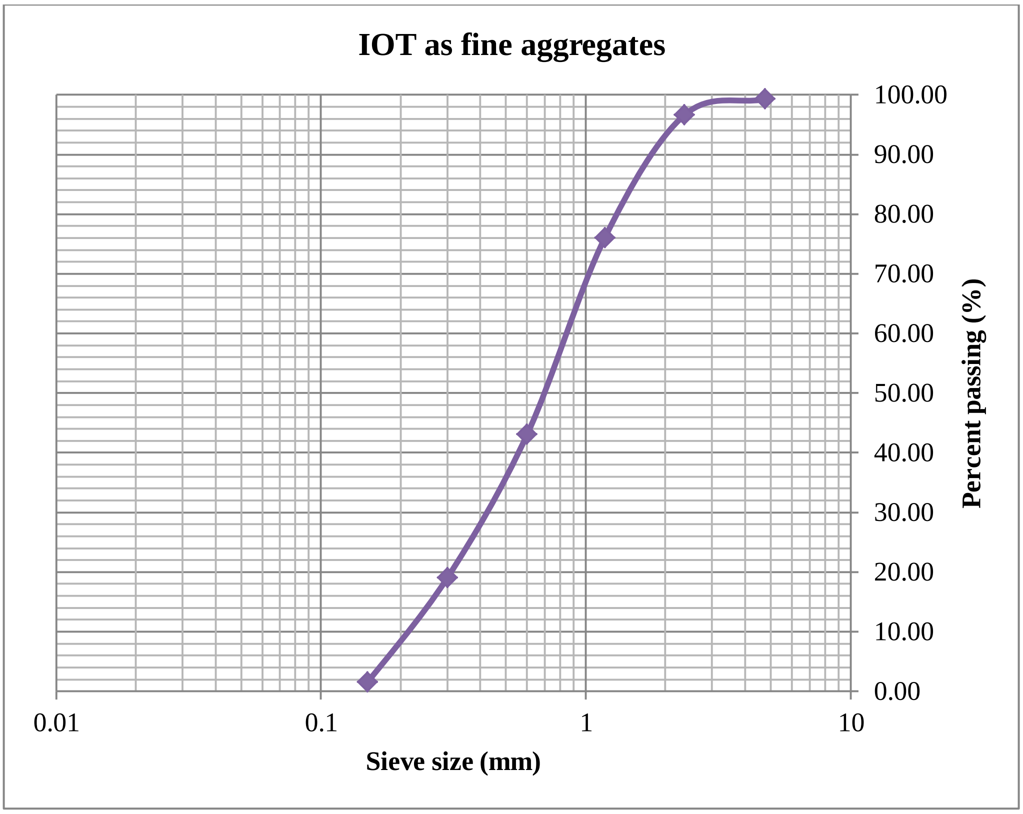


Fig. 3.4 Grading curve of Iron Ore Tailings (IOT) (Fine aggregate)

Fineness modulus = 2.6

Since the fineness modulus of IOT is 2.6, the IOT can be considered as replacement for fine sand, as the range of fineness modulus to be considered as fine according to IS 383 is 2.2~2.6.

d) Expanded Perlite (EP)

Expanded perlite was procured from M/s Keltech Energies Ltd. Karnataka, India. It is naturally occurring siliceous volcanic rock and it expands 15 times its original volume subject to heat. The properties of expanded perlite are, it is white in colour with pH of 7 and melting point at 1200 °C, with rough density of 70 kg/m^3.

3.2.4 Water

The amount of water in concrete mix has a direct effect on the strength development of the mixture. Sufficient water must be added to lubricate the solids in the mixture. Tap water was used for concreting.

3.2.5 Superplasticizer

Superplasticizer, also known as high range water reducer, is a chemical admixture used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (gravel, coarse and fine sands) and to improve the flow characteristics of concrete.

Sulfonated naphthalene formaldehyde polymer admixture ("Conplast SP 430") supplied by FOSROC, Chemicals (India) Pvt. Ltd. is used to improve the workability of concrete. Properties of super-plasticizer are given in Table 3.11.

Table 3.11 Properties of Conplast SP 430

Specific Gravity	1.20
Chloride Content	Nil
Solid content (%)	40
Operating Temperature (°C)	10 to 40
Colour	Dark brown liquid

3.3 Chemical Composition by X-Ray Fluorescence (XRF)

Chemical analysis of the marginal materials used in the present research work viz., Waste Rock (WR) and Iron Ore Tailings (IOTs), Alccofine and Expanded Perlite are discussed in this section.

A characterization technique, X-Ray Fluorescence (XRF) has become a better technique for elemental analysis. XRF involves exposing a material sample to X-ray light, which excites the elements present in the sample and when it returns to the ground state, the elements emit X-ray light. The light radiated as the elements are in their ideal state, unique to the specific elements present in the sample and measuring the fluorescence makes it possible to calculate the precise chemical composition of the sample. XRF analysis is non-destructive, quick and simple to perform resulting in precise results.

In the present research work, XRF analysis is conducted on WR, IOT and alccofine samples. Table 3.12 shows the major and minor metal oxides present in the samples.

Based on the XRF analysis, major components present in WR samples, are Silicon dioxide (SiO_2)- 51.861%, Iron oxide (Fe_2O_3)- 23.52%, Aluminium oxide (Al_2O_3)- 4.643%, Calcium oxide (CaO)- 4.643%. In the case of IOT sample, the major components are Silicon dioxide (SiO_2) - 49.750%, Iron oxide (Fe_2O_3)- 27.030%, Aluminium oxide (Al_2O_3)- 7.377%, Calcium oxide (CaO)- 4.057%. Alccofine consists of major composition are: Silica dioxide (SiO_2) - 34.4%, Aluminium oxide (Al_2O_3)- 21.6%, Calcium oxide (CaO)- 34% and Magnesium Oxide (MgO)-6.6%.

Table 3.12 Chemical composition by X-ray Florescence (XRF)

Chemical composition (%)	WR	IOT	Alccofine
SiO_2	51.861	49.750	34.4
Al_2O_3	4.643	7.377	21.6
Fe_2O_3	23.52	27.030	1.1
CaO	4.643	4.057	34
MnO	0.803	0.171	-
K_2O	0.131	0.500	-
ZnO	-	0.100	-
CuO	0.141	0.200	-
PbO	-	0.400	-
MgO	6.347	3.109	6.6
Na_2O	1.402	-	-
P_2O_5	0.179	-	-
SO_3	0.39	-	-
TiO_2	1.449	-	-
Cr_2O_3	0.104	-	-
NiO	0.105	-	-
pH	7.5	8.030	-
Electrical conductivity (mS)	0.238	0.329	-

3.4 Mix Design

Designing an appropriate mix for a particular strength and workability is very important for assessing the properties of the materials used in concrete. Each material will influence the properties of concrete in its own way. Concrete mix for M40 grade was designed following the IS 10262:2009. The total binder content is restricted to 425 kg/m^3, with water/binder ratio of 0.35, 0.40 and 0.45 for coarse aggregate: fine aggregate ratio of 0.64:0.36. The mixes are designed to achieve a slump value of 25-50mm. A super plasticizer quantity of 1.0% (by weight of binder content) is added to the mix to arrive at the designated slump. Mix proportions for concrete mixes are estimated for three different compositions.

Waste rock (WR) and iron ore tailings (IOT) were replaced partially as coarse and fine aggregates respectively in two different mixes i.e., 0%, 10%, 20%, 30%, 40% and 50% for 3, 7 and 28 days. This set of mixes is varied with varying w/c from 0.35, 0.40 and 0.45 as shown in Table 3.13(a) and Table 3.13(b).

With the experimental investigation from the previous mix compositions, the need to enhance the strength properties of concrete mixes with WR and IOT respectively was essential. Hence, alccofine is added as binder materials by 10% for varying WR and IOT i.e., 0%, 10%, 20%, 30%, 40% and 50% and cured for 3, 7, 28 and 56 days for two different mixes respectively. This set of mixes is varied with varying w/c from 0.35, 0.40 and 0.45 as shown in Table 3.13(c) and Table 3.13(d).

Further, concrete mixes with WR-alccofine and IOT alccofine were found to be high density concrete so to reduce the density, expanded perlite (EP) which is a density controller were added in varying percentages i.e., 0%, 2.5%, 5.0%, 7.5% and 10% as fine aggregates and cured for 3, 7, 28 and 56 days. This mix consists of optimum percentage obtained from the second set of mix proportions and then EP is varied for varying mix percentages, curing days and w/c at 0.35, 0.40 and 0.45.

Table 3.13 Details of mix proportions of different concrete mixes

Table 3.13(a) Mix proportion for Waste Rock (WR) -concrete

Mix	Cement (Kg)	Coarse aggregates (Kg)	Fine aggregates (Kg)	Water-cement ratio	Superplasticizer (% by wt. of cement)	WR (Kg)
WR1-0	445	1066.00	789	0.35	0.5	-
WR1-10		946.25			0.5	183.50
WR1-20		858.32			0.5	214.58
WR1-30		733.05			0.5	328.30
WR1-40		647.91			0.5	431.94
WR1-50		541.67			0.5	541.67
WR2-0	445	1081.00	834	0.40	0.5	-
WR2-10		954.21			0.5	196.85
WR2-20		864.86			0.5	223.30
WR2-30		756.76			0.5	334.90
WR2-40		648.65			0.5	446.60
WR2-50		540.54			0.5	558.20
WR3-0	445	1103.00	85061	0.45	0.5	-
WR3-10		985.52			0.5	201.20
WR3-20		887.92			0.5	221.98
WR3-30		779.45			0.5	334.04
WR3-40		670.26			0.5	446.84
WR3-50		560.34			0.5	560.34

Table 3.13(b) Mix proportion for Iron Ore Tailings (IOT) -concrete

Mix	Cement (Kg)	Alccofine (Kg)	Coarse aggregates (Kg)	Fine aggregates (Kg)	Water-cement ratio	Super-plasticizer (% by wt. of cement)	IOT (Kg)
IOT1-0	445	50	1066	789.00	0.35	0.5	-
IOT1-10				711.00		1	97.00
IOT1-20				660.00		1	165.00
IOT1-30				590.10		1	252.90
IOT1-40				516.60		1	344.40
IOT1-50				439.50		1	439.50
IOT2-0	386	43	1120	796.00	0.40	0.5	-
IOT2-10				716.00		1	97.50
IOT2-20				636.85		1	195.18
IOT2-30				557.25		1	292.76
IOT2-40				477.64		1	390.36
IOT2-50				398.03		1	487.96
IOT3-0	346	39	1116.5	861.30	0.45	0.5	-
IOT3-10				775.00		1	105.58
IOT3-20				720.16		1	180.04
IOT3-30				641.69		1	275.01
IOT3-40				563.48		1	375.65
IOT3-50				479.30		1	479.30

Table 3.13(c) Mix proportion for Waste Rock (WR)-alccofine-concrete

Mix	Cement (Kg)	Alccofine (Kg)	Coarse aggregates (Kg)	Fine aggregates (Kg)	Water-cement ratio	Super-plasticizer (% by wt. of cement)	WR (Kg)
WR1A-0	445	50	1066.00	789	0.35	0.5	-
WR1A-10			948.21			0.5	182.24
WR1A-20			858.32			0.5	214.58
WR1A-30			733.05			0.5	328.30
WR1A-40			647.91			0.5	431.94
WR1A-50			541.67			0.5	541.67
WR2A-0	386	43	1081.00	834	0.40	0.5	-
WR2A-10			967.58			0.5	198.25
WR2A-20			864.86			0.5	223.30
WR2A-30			756.76			0.5	334.90
WR2A-40			648.65			0.5	446.60
WR2A-50			540.54			0.5	558.20
WR3A-0	347	39	1103.00	850.61	0.45	0.5	-
WR3A-10			986.52			0.5	202.54
WR3A-20			887.92			0.5	221.98
WR3A-30			779.45			0.5	334.04
WR3A-40			670.26			0.5	446.84
WR3A-50			560.34			0.5	560.34

Table 3.13(d) Mix proportion for Iron Ore Tailings (IOT)-alccofine-concrete

Mix	Cement (Kg)	Alccofine (Kg)	Coarse aggregates (Kg)	Fine aggregates (Kg)	Water-cement ratio	Super-plasticizer (% by wt. of cement)	IOT (Kg)
IOT1A-0	445	50	1066	789.00	0.35	0.5	-
IOT1A-10				711.00		1	97.00
IOT1A-20				660.00		1	165.00
IOT1A-30				590.10		1	252.90
IOT1A-40				516.60		1	344.40
IOT1A-50				439.50		1	439.50
IOT2A-0	386	43	1120	796.00	0.40	0.5	-
IOT2A-10				716.00		1	97.50
IOT2A-20				636.85		1	195.18
IOT2A-30				557.25		1	292.76
IOT2A-40				477.64		1	390.36
IOT2A-50				398.03		1	487.96
IOT3A-0	346	39	1116.5	861.30	0.45	0.5	-
IOT3A-10				775.00		1	105.58
IOT3A-20				720.16		1	180.04
IOT3A-30				641.69		1	275.01
IOT3A-40				563.48		1	375.65
IOT3A-50				479.30		1	479.30

Table 3.13(e) Estimation of number of samples required for different concrete mixes with alccofine.

w/c			**0.35, 0.40, 045**				
IOT-alccofine concrete mix (0%, 10%, 20%, 30%, 40%, 50%)							
			Curing days				
Type of Test	**Shape of samples**	**Dimension (mm)**	**3**	**7**	**28**	**56**	**Total**
Compressive strength	Cube	100*100*100	54	54	54	54	216
Splitting tensile strength	Cylinder	150*300	-	-	54	54	108
Flexural strength	Beams	100*100*500	-	-	54	54	108
Sub-total							*432*
WR-alccofine concrete mix (0%, 10%, 20%, 30%, 40%, 50%)							
Compressive strength	Cube	100*100*100	54	54	54	54	216
Splitting tensile strength	Cylinder	150*300	-	-	54	54	108
Flexural strength	Beams	100*100*500	-	-	54	54	108
Sub-total							*432*
EP concrete mix (0%, 2.5%, 5.0%, 7.50%, 10.0%)							
Compressive strength	Cube	100*100*100	45	45	45	45	180
Splitting tensile strength	Cylinder	150*300	-	-	45	45	90
Flexural strength	Beams	100*100*500	-	-	45	45	90
Sub-total							*360*
TOTAL							**1224**
Total number of samples prepared							***2088***

3.5 Preparation of Concrete Samples

Concrete specimens of number 216 cubes (150mm*150mm*150mm), 108 cylinders (150mm in diameter and 300mm in length) and 108 beams (100mm*100mm*500mm) were casted to study hardened concrete properties (compressive strength, spilt-tensile strength and flexural strength respectively) for each concrete mix. Concrete was mixed in drum mixer. Coarse aggregate, fine aggregate, WR, IOT and cement and alccofine were added and dry mixed till uniform mix was seen for each case of mix proportion respectively as discussed in section 3.4. 60% of water was added and mixed again, and then the superplasticizer was mixed with remaining 40% water and then added to concrete. Once the uniform mix was obtained, fresh concrete properties were studied (slump of concrete was measured and observed to check if there was any segregation or bleeding).

Concrete was loaded into moulds and sufficient compaction was given using table concrete vibrator. Specimens were de-moulded after 24 hours and immersed in water for curing for required duration. For hardened concrete, compressive strength was determined at 3, 7 and 28 days of curing age. Splitting tensile strength and flexural strength were determined at 28 curing days for WR and IOT concrete mixes and for WR-alccofine, IOT-alccofine and EP-concrete mixes, compressive strength was determined at 3, 7, 28 and 56 days of curing. Splitting tensile strength and flexural strength were determined at 28 and 56 curing days.

Fig. 3.6 illustrates the concrete mix with WR-alccofine and Fig. 3.7 and Fig. 3.8 illustrate the samples placed and compacted into cubes, cylinders and beams to test the cured concrete specimens for the properties.

Similarly, Fig. 3.9 illustrates the mix concrete with IOT-alccofine and Fig. 3.10 illustrates the samples placed and compacted into cubes to test the cured concrete specimens for the properties.

Fig. 3.5 Illustration for concrete mix with Waste Rock (WR) -alccofine

Fig. 3.6 Concrete mix casting with Waste Rock (WR)-alccofine in beams and cylinder moulds

Fig. 3.7 Concrete mix casting with Waste Rock (WR)-alccofine in cubes and cylinder moulds

Fig. 3.8 Illustration for concrete mix with Iron Ore Tailings (IOT)-alccofine

Fig. 3.9 Concrete mix casting with Iron Ore Tailings (IOT)-alccofine in cube moulds

3.6 Fresh and Hardened Properties on Concrete

After proper mixing of the ingredients, the specimens of different dimensions are prepared in order to test the mechanical properties. All the tests were conducted as per relevant IS codes at different curing ages.

3.6.1 Workability on fresh concrete mixes

Workability of concrete gives an idea about the mixing ability, transportability, moulding ability and compacting ability of concrete. Workability of concrete was measured in terms of slump using the slump cone test. Fresh concrete mix was also checked for signs of segregation and bleeding. Necessary corrections were made to the mix proportioning based on the observations on trial mixes. Fig. 3.11 shows a view of slump test performed on concrete.

Fig. 3.10 Slump test on Iron Ore Tailings (IOT) concrete

3.6.2 Mechanical properties on hardened concrete

Hardened concrete was tested for its mechanical properties which included compressive strength, splitting tensile strength and flexural strength.

a) Compression test

The compressive strength is the most common performance measured and used to study the properties of concrete. It gives an idea about the mechanical properties of concrete. The strength of concrete depends on various factors like curing age, degree of hydration, rate of loading, method of testing, specimen geometry, properties and proportions of the constituent materials. Compression testing of cube specimens of size (150mm*150mm*150mm) was carried out in a compression testing machine of capacity 2000 kN, as per IS 516-1959. The load was applied without shock at the rate of 140 kg/sq.cm/min. Set of six cubes were tested for each of the mix to determine their compressive strength at 3, 7, 14 and 28 days. Ultimate load at which the specimens failed was noted down to find the compressive strength. Rupture surface of the specimens after failure were visually inspected. Fig. 3.12 shows a view of a specimen after failure in compression.

Fig. 3.11 Illustration of compression test on concrete cubes

b) Flexural strength

The plain beam specimens were tested under third-point loading. The flexural strength testing apparatus consisted of a loading frame fitted with a manually operated hydraulic actuator. The hydraulic actuator used for the loading had a load capacity of 230 kN. An average loading rate of 1 kN/s was maintained throughout the testing procedure. The loads were positioned within the middle third 150 mm of the specimen, thus maintaining a loading span of 450 mm during the test. The modulus of rupture of the beams was determined at age 28 days curing after the test depending on the place of occurrence of the failure fracture.

Under third-point loading, two scenarios are possible;

a) For fracture occurring within the middle third, the Modulus of rupture (MOR) is calculated as;

$$f_b = (Pl)/(bd^2) \quad \text{for } a > 133.3 \text{ mm} \text{ -----------} \qquad (3.1)$$

b) For fracture outside the middle third

$$f_b = (3Pa)/(bd^2) \quad \text{for } 110 \text{ mm} < a < 133.3 \text{ mm} \qquad (3.2)$$

Where, a = distance between the line of fracture and the nearer support

P = maximum load

l = span of the beam

‘b’ and ‘d’ are the cross sectional dimensions

Fig. 3.13 shows the view of specimens marked for two point flexure test, testing of beam for flexural strength, view of beam after failure under flexural load and measurement of distance between line of fracture and nearest support in specimen subjected to flexural load respectively (Figure 3.14).

Fig. 3.12 Flexural testing of beam

Fig. 3.13 View of concrete beam with marking for testing

c) Splitting tensile strength

Splitting tensile strength test is a well-known indirect test used for determining the tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. Due to the compression loading, a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter. Splitting tensile test is carried out as per IS: 5816-1999. Loading is done at a rate of 1.2- 2.4 MPa/min.

Splitting tensile strength is calculated using the formula

$$f_t = (2P/\pi LD) \tag{3.3}$$

Where, P = load at failure

L = length of the cylinder

D = diameter of the cylinder

Fig. 3.15 illustrates the splitting tensile strength test performed on cylinder.

Fig. 3.14 Splitting tensile test on cylindrical sample

3.7 Durability Test on Concrete Mixes

Concrete based materials ascertain various applications in construction industry for instance, structures, water supply units, mechanical foundation, and so forth. Although concrete results in excellent mechanical properties, it should also resist the violent environmental conditions. The violent environment is usually aqueous in nature that may either be natural occurring (such as sea waters, soft waters) or may be man-made (such as industrial, waste water or polluted environments). Under such environments, concrete undergoes degradation through the processes of ion exchange and chemical reactions, thus leading to changes in the matrix microstructure and ultimately reduction in the strength of the material. In this section, the durability properties of WR-alccofine, IOT-alccofine and EP concrete are evaluated. A durability property by Rapid Chloride Permeability Test (RCPT) was conducted and the details are discussed in this section.

3.7.1 Rapid chloride permeability test

Rapid Chloride Permeability test is conducted as per AASHTO T 277 or ASTM C 1202**.** It is the test for chloride ions**.** This test is performed to check the ability of concrete to resist chloride ion penetration. This test enables to predict the service life of concrete structures. It can also be used for durability-based quality control purposes.

In this test, constant voltage (V) is applied on a concrete specimen for 6 hours and the current (i) passing through the concrete is recorded to find the coulombs. The experimental set for RCPT is shown in Fig. 3.16.

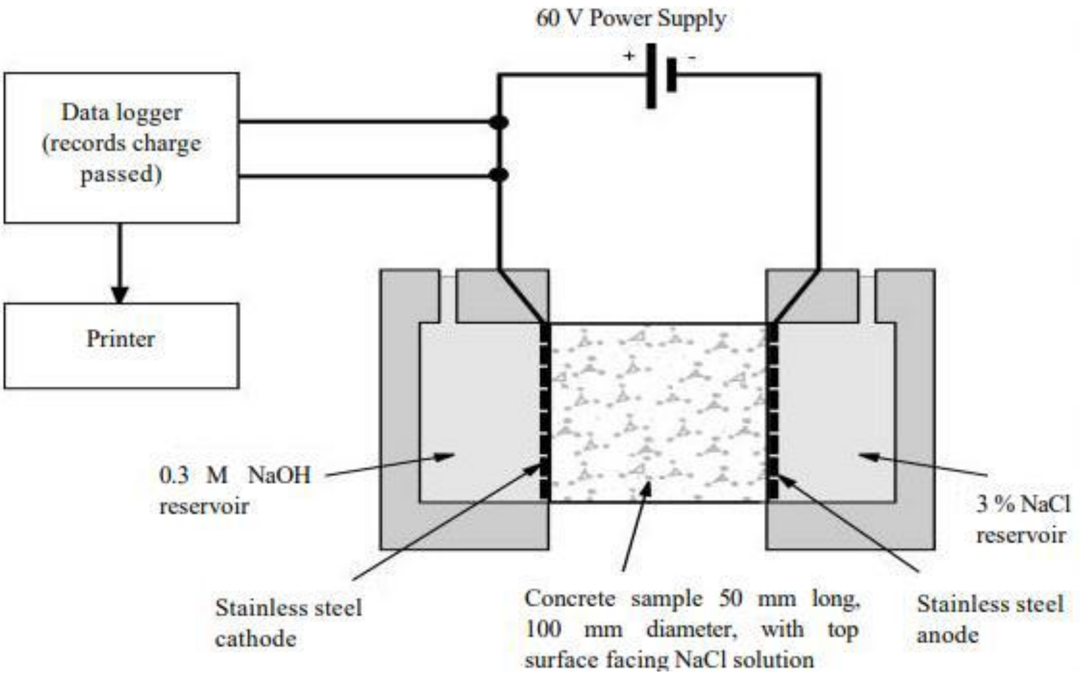


Fig. 3.15 Rapid Chloride Permeability test setup (ASTM C1202)

3.8 Statistical Analysis for Concrete Mixes

To propose backward elimination method by empirical equations, statistical methods were used. Multiple regression analysis is one of the methods widely used for modelling and analysing the experimental results obtained from laboratory studies. The analysis is conducted to derive a relationship between the predator variables and response variables. The performance of the model depends on various factors that act in a complex manner. Analysis of variance (ANOVA) is used to find the input parameter significantly affecting the desired response. In the present paper, MINITAB 17 software is used for the analysis.

The values of VAF (Eq. 1) and Root Mean Square Error (RMSE) (Eq. 2) indices were calculated to compare the performance of the prediction capacity of predictive models developed in the study. Mean absolute percentage error (MAPE) (Eq. 3) which is a measure of accuracy in a fitted series value in statistics was also used to check the prediction performances of the models. MAPE usually expresses accuracy as a percentage (Rajesh Kumar et al. 2013).

$$\text{VAF} = \left[1 - \frac{\text{var}(OCS - PCS)}{\text{var}(OCS)} \right] \quad (3.3)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(OCS - PCS)^2} \quad (3.4)$$

$$\text{MAPE} = \frac{1}{N}\sum_{i=0}^{N}\left|\frac{OCS - PCS}{PCS}\right| \text{x } 100 \quad (3.5)$$

Where, VAF= Variance Accounted For; RMSE= Root Mean Square Error; MAPE= Mean Absolute Percentage Error; OCS= Observed Compressive Strength; PCS= Predicted Compressive Strength.

3.9 Experimental Investigations

Production of concrete was designed for various compositions. Fırstly, iron ore mine waste rock (WR) and tailings (IOT) were partially substituted for coarse and fine aggregates respectively. Secondly, alccofine was replaced partially as binder material to the same mix proportions to enahance the properties of concrete. Finally, for the optimum mix of iron ore waste rock (WR) and tailings (IOT) respectively, the density was found to be higher than the conventional concrete. Hence, expanded perlite (EP) a density controller was used as an additive to the optimum percentage of iron ore waste rock (WR) and tailings (IOT) and with varying percentages of expanded perlite (EP). For all the above cases, fresh (workability test) and hardenend properties of concrete i.e., compression, splitting tensile and flexural strength were determined. Durability properties viz., rapid chloride permeability test (RCPT) were determined. To compare the experimental results and to validate, statistical analysis was done.

3.9.1 Iron Ore Waste Rock (WR)

Iron Ore Waste Rock (WR) was partially replaced as coarse aggregates from 0%, 10%, 20%, 30%, 40% and 50% in the production of concrete for M40 grade. The fresh and hardened state of concrete was determined for the given percentage of replacements for 3, 7 and 28 curing days and for varying water-cement (w/c) ratio of 0.35, 0.40 and 0.45. For each mix, three samples were tested ie., w.r.t the percentage replacement, curing days and w/c and the average values are considered.

a. Workability of concrete with WR as partial replacement of coarse aggregates in the production of concrete

Workability of concrete was performed according to the suggested method in IS 1199:1959. Workability of concrete with varying percentages of WR at different w/c of 0.35, 0.40 and 0.45 were tested for compactiblity using a slump cone. The results are presented in Table 3.14.

Table 3.14 Workability with partial replacement of coarse aggregates with iron ore waste rock (WR) in concrete

Mix percentage	**w/c**		
	0.35	**0.40**	**0.45**
	Slump (mm)		
WR 0	35	38	40
WR 10	32	35	37
WR 20	30	33	35
WR 30	28	30	32
WR 40	28	30	32
WR 50	25	28	30

Notation: WR- Iron Ore Waste Rock

b. Compressive strength of concrete with WR as partial replacement of coarse aggregates in the production of concrete

Compressive strength test was conducted as per IS: 516-1959 for concrete with varying percentages of WR from 0% to 50% with 10% intervals at 3, 7, and 28 curing days for 0.35, 0.40 and 0.45 w/c. For each mix, 3 trial samples were casted and cured and the compressive strength test was conducted and the average values are presented in Table 3.15.

c. Splitting tensile strength of concrete with WR as partial replacement of coarse aggregates in the production of concrete

The spilt tensile strength test was conducted as per IS 5816:1999. Three trial set of samples of 150x300mm concrete cylinders were casted and cured for varying WR percentages from 0-50% with 10% intervals and varying w/c of 0.35, 0.40 and 0.45 w/c at 28 days curing and tested for splitting tensile strength and the values are shown in Table 3.16.

Table 3.15 Compressive strength with partial replacement of coarse aggregates with iron ore waste rock (WR) in concrete

w/c	**Mix percentage**	**Compressive Strength (MPa)**		
		3 days	**7 days**	**28 days**
0.35	WR1-0	21.25	25.55	43.18
	WR1-10	23.45	35.18	53.14
	WR1-20	25.14	37.15	56.34
	WR1-30	26.85	38.32	57.42
	WR1-40	24.25	39.18	58.42
	WR1-50	22.53	37.08	57.05
0.40	WR2-0	19.93	22.81	41.26
	WR2-10	27.12	34.05	52.45
	WR2-20	29.53	35.61	55.14
	WR2-30	23.82	34.86	54.86
	WR2-40	21.53	33.75	53.64
	WR2-50	20.00	32.41	51.72
0.45	WR3-0	17.56	20.15	41.00
	WR3-10	26.10	33.32	51.25
	WR3-20	20.14	34.58	53.45
	WR3-30	19.21	33.93	52.21
	WR3-40	18.98	33.52	51.00
	WR3-50	18.00	32.05	48.50

Notation: WR1- Iron ore waste rock at 0.35 w/c

WR2- Iron ore waste rock at 0.40 w/c

WR3- Iron ore waste rock at 0.45 w/c

d. Flexural strength of concrete with WR as partial replacement of coarse aggregates in the production of concrete

Flexural strength of concrete specimens was determined according to IS 516:1959 for all the mixes. Concrete beams of 100x100x500mm dimension were casted and cured for WR percentages from 0-50% with 10% interval at 28 days curing for 0.35, 0.40 and 0.45 w/c. Three trial specimens were casted for each mix and tested and the average strength values are presented in Table 3.17.

Table 3.16 Splitting tensile strength with partial replacement of coarse aggregates with iron ore waste rock (WR) in concrete

Mix percentage	Split tensile strength (MPa) (28 days)		
	0.35	**0.40**	**0.45**
WR-0	2.78	2.67	2.59
WR-10	2.92	2.84	2.80
WR-20	3.18	3.11	2.75
WR-30	3.24	3.21	2.70
WR-40	3.39	3.18	2.68
WR-50	3.30	3.12	2.63

Notation: WR- Iron ore waste rock

Table 3.17 Flexural strength with partial replacement of coarse aggregates with iron ore waste rock (WR) in concrete

Mix percentage	Flexural strength (MPa) for 28 days		
	0.35	**0.40**	**0.45**
WR-0	5.00	4.84	4.62
WR-10	5.14	5.05	5.02
WR-20	5.20	5.17	5.13
WR-30	5.22	5.14	5.10
WR-40	5.32	5.10	5.04
WR-50	5.28	5.07	4.92

Notation- WR- Iron ore waste rock

3.9.2 Iron Ore Tailings (IOT)

Iron Ore Tailings (IOT) were partially replaced as fine aggregates for varying mix proportion of 0%, 10%, 20%, 30%, 40% and 50% in the production of concrete for M40 grade. The fresh and hardened state of concrete was determined for the given percentage of replacements at 3, 7 and 28 curing days for varying w/c ratio of 0.35, 0.40 and 0.45. For each mix, three samples were tested ie., w.r.t the percentage replacement, curing days and w/c and the average values are considered.

(a) Workability of concrete with IOT as partial replacement of fine aggregates in the production of concrete

The compactability of concrete is determined in fresh state using a slump cone as per IS 1199:1959. The slump test for concrete mixes with IOT as partial replacement of fine aggregates from 0-50% with 10% intervals at varying w/c of 0.35, .0.40 and 0.45 were observed and presented in Table 3.18.

(b) Compressive strength of concrete with IOT as partial replacement of fine aggregates in the production of concrete

Compressive strength test was carried out as per IS: 516-1959 on 100x100x100 mm specimens casted and cured for partial replacement of fine aggregates with IOT at 3, 7 and 28 days curing at varying w/c of 0.35, 0.40 and 0.45. Three trial cubes were casted for each mix proportion, curing days and w/c and the specimens were tested and the average values obtained are given in Table 3.19.

(c) Splitting tensile strength of concrete with IOT as partial replacement of fine aggregates in the production of concrete

The spilt tensile strength test of cylindrical concrete specimens of dimension 150x300mm were casted with varying IOT replacement from 0-50% with10% interval at 28 days curing for varying w/c of 0.35, 0.40 and 0.45 w/c were tested as per IS 5816:1999. Three sets of specimens were casted for each varying mix proportion, curing days and w/c and the average values are presented in Table 3.20.

Table 3.18 Workability with partial replacement of fine aggregates with iron ore tailings (IOT) in concrete

Mix percentage	w/c		
	0.35	0.4	0.45
	Slump (mm)		
IOT-0	30	33	35
IOT-10	28	30	33
IOT-20	26	29	31
IOT-30	22	25	28
IOT-40	15	20	25
IOT-50	0	0	10

Table 3.19 Compressive strength with partial replacement of fine aggregates with iron ore tailings (IOT) in concrete

w/c	Mix	Compressive Strength (MPa)		
		3 days	7 days	28 days
0.35	IOT1-0	21.25	25.55	43.18
	IOT1-10	25.15	28.56	48.45
	IOT1-20	29.11	33.85	50.44
	IOT1-30	33.77	37.33	52.11
	IOT1-40	26.52	28.22	47.03
	IOT1-50	18.59	27.33	44.07
0.4	IOT2-0	19.93	22.81	41.26
	IOT2-10	22.14	25.65	44.85
	IOT2-20	24.74	30.67	46.37
	IOT2-30	23.82	29.14	45.42
	IOT2-40	21.53	26.25	43.11
	IOT2-50	20.00	25.85	42.53
0.45	IOT3-0	17.56	20.15	41.00
	IOT3-10	21.42	24.24	43.14
	IOT3-20	20.14	23.24	42.32
	IOT3-30	19.21	22.14	41.52
	IOT3-40	18.98	21.45	41.00
	IOT3-50	18.00	20.98	40.54

(d) Flexural strength of concrete with IOT as partial replacement of fine aggregates in the production of concrete

Flexural strength of concrete specimen was determined according to IS 516:1959 for all the mixes. Concrete beams of 100x100x500mm dimension were casted and cured for IOT percentages from 0-50% with 10% interval at 28 days curing for 0.35, 0.40 and 0.45 w/c. Three trial specimens were casted for each mix and tested and the average strength values are presented in Table 3.21.

Table 3.20 Splitting tensile strength with partial replacement of fine aggregates with iron ore tailings (IOT) in concrete

Mix Proportion	**Splitting Tensile Strength (MPa) (28 days)**		
(w/c)	**0.35**	**0.4**	**0.45**
IOT-0	2.78	2.67	2.59
IOT-10	3.74	3.62	3.54
IOT-20	3.82	3.71	3.51
IOT-30	3.91	3.68	3.47
IOT-40	3.86	3.62	3.42
IOT-50	3.84	3.58	3.38

Table 3.21 Flexural strength with partial replacement of fine aggregates with iron ore tailings (IOT) in concrete

Mix Proportion	**Flexural Tensile Strength (MPa) (28 days)**		
(w/c)	**0.35**	**0.4**	**0.45**
IOT-0	5.00	4.84	4.62
IOT-10	5.23	5.19	5.10
IOT-20	5.27	5.21	5.02
IOT-30	5.21	5.15	4.93
IOT-40	5.18	5.08	4.84
IOT-50	5.27	5.01	4.76

Notation- IOT- Iron ore tailings

3.9.3 Iron ore waste rock (WR)- alccofine concrete

Iron ore waste rock is used as partial replacement of coarse aggregates and the properties of concrete are discussed in section 3.7.1. Based on the strength values, the present research focuses on enhancing the properties of concrete with addition of admixtures to the WR mix composition. Alccofine is a micro fine particle considered as partial replacement of binder material by 10%. The fresh and hardened properties of concrete with varying WR composition from 0-50% with 10% intervals and 10% alccofine as binder replacement for three different w/c (0.35, 0.40 and 0.45) are determined and discussed in this section.

(a) Workability of concrete with WR-alccofine in the production of concrete

Workability of concrete is determined in fresh state using a slump cone as per IS 1199:1959. The slump test for concrete mixes with WR as partial replacement of coarse aggregates from 0-50% with 10% intervals at varying w/c of 0.35, 0.40 and 0.45 were observed and presented in Table 3.22.

Table 3.22 Workability with partial replacement of coarse aggregates with iron ore waste rock (WR) and alccofine as binder (WR-alccofine) in concrete

Mix Proportion	**w/c**		
	0.35	**0.4**	**0.45**
	Slump (mm)		
WRA-0	40	45	50
WRA-10	40	45	50
WRA-20	40	45	50
WRA-30	40	45	50
WRA-40	35	40	45
WRA-50	35	40	45

Notation: WRA- Iron ore waste rock with alccofine at 0.35 w/c

WRA- Iron ore waste rock with alccofine at 0.40 w/c

WRA- Iron ore waste rock with alccofine at 0.45 w/c

(b) Density

The density of concrete was determined for concrete mixes with WR varying from 0-50% with 10% intervals and 10% alccofine as binder replacement at 3, 7, 28 and 56 curing days for 0.35, 0.40 and 0.45 w/c. The density observed is presented in Table 3.23.

(c) Compressive strength of concrete with WR-alccofine in the production of concrete

Compressive strength test was carried out as per IS: 516-1959 on 100mm^3 specimens casted and cured for partial replacement of coarse aggregates with WR from 0-50% with 10% intervals and alccofine as binder replacement of 10% and the specimens are cured for 3, 7 and 28 days at varying w/c of 0.35, 0.40 and 0.45 Three trial cubes were casted for each mix proportion, curing days and w/c and the specimens were tested and the average values obtained are presented in Table 3.24.

(d) Splitting tensile strength of concrete with WR-alccofine in the production of concrete

The spilt tensile strength test of cylindrical concrete specimens of dimension 150x300mm were casted with varying WR replacement from 0-50% with10% interval and 10% alccofine as binder replacement in concrete and cured at 28 and 56 days for varying w/c of 0.35, 0.40 and 0.45 and tested as per IS 5816:1999. Three set of specimens were casted for each varying mix proportion, curing days and w/c and the average values are represented in Table 3.25.

Table 3.23 Density with partial replacement of coarse aggregates with iron ore waste rock (WR) and alccofine as binder (WR-alccofine) in concrete

w/c	Mix	Density (kg/m^3)			
		3 days	7 days	28 days	56 days
0.35	WR1A-0	2526.33	2552.33	2547.33	2594.33
	WR1A-10	2526.33	2552.33	2573.33	2582.33
	WR1A-20	2590.00	2643.33	2680.33	2687.33
	WR1A-30	2619.67	2653.33	2684.33	2690.33
	WR1A-40	2619.00	2647.33	2645.67	2652.33
	WR1A-50	2623.67	2689.67	2693.67	2694.33
0.40	WR2A-0	2493.33	2534.00	2546.67	2584.67
	WR2A-10	2526.33	2552.33	2573.33	2582.33
	WR2A-20	2589.33	2623.67	2632.67	2652.00
	WR2A-30	2608.67	2626.67	2639.33	2661.00
	WR2A-40	2616.67	2647.33	2645.67	2652.33
	WR2A-50	2593.67	2621.67	2635.33	2654.00
0.45	WR3A-0	2470.00	2515.33	2525.33	2562.67
	WR3A-10	2475.00	2571.33	2594.33	2621.33
	WR3A-20	2482.33	2581.00	2604.33	2627.67
	WR3A-30	2525.67	2584.00	2616.00	2639.00
	WR3A-40	2517.00	2562.33	2609.33	2626.00
	WR3A-50	2490.33	2556.33	2587.33	2600.67

Notation: WR1A- Iron ore waste rock with alccofine at 0.35 w/c

WR2A- Iron ore waste rock with alccofine at 0.40 w/c

WR3A- Iron ore waste rock with alccofine at 0.45 w/c

Table 3.24 Compressive strength with partial replacement of coarse aggregates with iron ore waste rock (WR) and alccofine as binder (WR-alccofine) in concrete

w/c	Mix	Compressive Strength			
		3 days	7 days	28 days	56 days
0.35	WR1A-0	32.00	47.33	60.33	68.00
	WR1A-10	36.33	48.00	60.67	68.00
	WR1A-20	45.67	49.33	61.00	68.33
	WR1A-30	48.00	54.00	64.00	71.00
	WR1A-40	51.00	56.00	66.00	73.00
	WR1A-50	53.00	57.00	68.00	75.33
0.40	WR2A-0	30.67	41.33	57.33	65.00
	WR2A-10	41.67	46.00	57.00	65.33
	WR2A-20	43.00	48.00	59.00	66.00
	WR2A-30	45.67	52.00	61.33	68.33
	WR2A-40	47.33	56.00	64.33	72.00
	WR2A-50	44.33	53.00	62.00	69.00
0.45	WR3A-0	28.67	34.33	60.33	68.00
	WR3A-10	34.33	45.33	53.33	59.00
	WR3A-20	36.33	45.33	54.00	60.33
	WR3A-30	39.00	48.33	58.00	64.00
	WR3A-40	37.33	46.00	58.00	61.67
	WR3A-50	35.33	43.00	56.00	60.00

Notation: WR1A- Iron ore waste rock with alccofine at 0.35 w/c

WR2A- Iron ore waste rock with alccofine at 0.40 w/c

WR3A- Iron ore waste rock with alccofine at 0.45 w/c

(e) Flexural strength of concrete with WR-alccofine in the production of concrete

The flexural strength of concrete specimen was determined according to IS 516:1959 for all the mixes. Concrete beams of 100x100x500mm dimension were casted and cured for IOT percentages from 0-50% with 10% interval and 10% binder at 28 days curing for 0.35, 0.40 and 0.45 w/c. Three trial specimens were casted for each mix and tested and the average strength values are represented in Table 3.26.

Table 3.25 Splitting tensile strength with partial replacement of coarse aggregates with iron ore waste rock (WR) and alccofine as binder (WR-alccofine) in concrete

w/c	Mix proportion	Split tensile strength (MPa)	
		28 days	56 days
0.35	WR1A-0	4.15	4.34
	WR1A-10	4.25	4.48
	WR1A-20	4.34	4.62
	WR1A-30	4.48	4.86
	WR1A-40	4.53	5.05
	WR1A-50	4.95	5.28
0.40	WR2A-0	4.01	4.20
	WR2A-10	4.10	4.29
	WR2A-20	4.20	4.53
	WR2A-30	4.44	4.62
	WR2A-40	4.67	5.14
	WR2A-50	4.48	4.86
0.45	WR3A-0	3.92	4.15
	WR3A-10	4.10	4.25
	WR3A-20	4.15	4.48
	WR3A-30	4.53	4.86
	WR3A-40	4.06	4.58
	WR3A-50	3.82	4.39

Notation: WR1A- Iron ore waste rock with alccofine at 0.35 w/c

WR2A- Iron ore waste rock with alccofine at 0.40 w/c

WR3A- Iron ore waste rock with alccofine at 0.45 w/c

Table 3.26 Flexural strength with partial replacement of coarse aggregates with iron ore waste rock (WR) and alccofine as binder (WR-alccofine) in concrete

w/c	Mix proportion	Flexural strength (MPa)	
		28 days	56 days
0.35	WR1A-0	6.27	6.40
	WR1A-10	6.40	6.67
	WR1A-20	6.87	6.93
	WR1A-30	7.07	7.27
	WR1A-40	6.80	7.40
	WR1A-50	6.93	7.67
0.40	WR2A-0	5.73	6.07
	WR2A-10	5.93	6.27
	WR2A-20	6.07	6.47
	WR2A-30	6.20	6.73
	WR2A-40	6.60	7.33
	WR2A-50	6.13	6.47
0.45	WR3A-0	5.60	5.87
	WR3A-10	5.80	6.20
	WR3A-20	6.20	6.40
	WR3A-30	6.33	6.60
	WR3A-40	5.87	6.47
	WR3A-50	5.67	6.07

Notation: WR1A- Iron ore waste rock with alccofine at 0.35 w/c

WR2A- Iron ore waste rock with alccofine at 0.40 w/c

WR3A- Iron ore waste rock with alccofine at 0.45 w/c

3.9.4 Iron ore waste tailings (IOT)- alccofine concrete

Iron ore tailings (IOT) are used as partial replacement of fine aggregates and the properties of concrete are discussed in section 3.7.2. Similar to the concrete based on WR, the present research focuses on enhancing the properties of concrete with addition of admixtures to the IOT mix composition. Alccofine is a micro fine particle considered as partial replacement of binder material by 10%. The fresh and hardened properties of concrete with varying IOT composition from 0-50% with 10% intervals and 10% alccofine as binder replacement for three different w/c (0.35, 0.40 and 0.45) at 3, 7, 28 and 56 curing days are determined and discussed in this section.

(a) Workability of concrete with IOT-alccofine in the production of concrete

The compactability of concrete is determined in fresh state using a slump cone as per IS 1199:1959. The slump test for concrete mixes with IOT as partial replacement of fine aggregates from 0-50% with 10% intervals at varying w/c of 0.35, 0.40 and 0.45 were observed and presented in Table 3.27.

Table 3.27 Workability with partial replacement of fine aggregates with iron ore tailings (IOT) and alccofine as binder (IOT-alccofine) in concrete

Mix percentage	w/c		
	0.35	**0.4**	**0.45**
	Slump (mm)		
IOTA-0	40	45	50
IOTA-10	35	40	45
IOTA-20	35	35	40
IOTA-30	30	30	37
IOTA-40	25	27	35
IOTA-50	20	25	30

Notation: IOTA : Iron Ore Tailings with alccofine

(b) Density

The density of concrete was determined for concrete mixes with IOT varying from 0-50% with 10% intervals and 10% alccofine as binder replacement at 3, 7, 28 and 56 curing days for 0.35, 0.40 and 0.45 w/c.

(c) Compressive strength of concrete with IOT-alccofine in the production of concrete

Compressive strength test was carried out as per IS: 516-1959 on $100mm^3$ specimens casted and cured for partial replacement of coarse aggregates with WR from 0-50% with 10% intervals and alccofine as binder replacement of 10% and the specimens are cured at 3, 7, 28 and 56 days at varying w/c of 0.35, 0.40 and 0.45 Three trial cubes were casted for each mix proportion, curing days and w/c and the specimens were tested and the average values are obtained represented in Table 3.29.

(d) Splitting tensile strength of concrete with IOT-alccofine in the production of concrete

The spilt tensile strength test of cylindrical concrete specimens of dimension 150x300mm were casted with varying WR replacement from 0-50% with10% interval and 10% alccofine as binder replacement in concrete and cured at 28 and 56 days for varying w/c of 0.35, 0.40 and 0.45 and tested as per IS 5816:1999. Three set of specimens were casted for each varying mix proportion, curing days and w/c and the average values are represented in Table 3.30.

(e) Flexural strength of concrete with IOT-alccofine in the production of concrete

The flexural strength of concrete beams of dimension 100x100x500mm was determined according to IS 516:1959 for the concrete mixes with IOT percentages varying from 0-50% with 10% interval at 28 an 56 days curing days and for varying w/c 0.35, 0.40 and 0.45 w/c. Three trial specimens were casted for each mix and tested and the average strength values are represented in Table 3.26.

Table 3.28 Density with partial replacement of fine aggregates with iron ore tailings (IOT) and alccofine as binder (IOT-alccofine) in concrete

w/c	Mix percentage	Density (kg/m^3)			
		3 days	7 days	28 days	56 days
0.35	IOT 0	2526.33	2552.33	2547.33	2594.33
	IOT 10	2531.33	2553.33	2567.33	2584.33
	IOT 20	2564.00	2555.33	2611.00	2615.67
	IOT 30	2574.00	2639.33	2644.67	2652.33
	IOT 40	2573.00	2584.67	2656.00	2665.67
	IOT 50	2566.33	2612.00	2563.67	2592.00
0.4	IOT 0	2493.33	2530.00	2546.67	2584.67
	IOT 10	2503.33	2533.33	2560.00	2590.00
	IOT 20	2526.67	2543.33	2594.67	2603.33
	IOT 30	2531.33	2580.00	2623.33	2690.33
	IOT 40	2522.67	2573.00	2574.67	2688.33
	IOT 50	2514.33	2558.00	2543.33	2644.00
0.45	IOT 0	2470.00	2515.33	2525.33	2562.67
	IOT 10	2502.37	2529.00	2546.67	2560.00
	IOT 20	2518.00	2529.67	2545.33	2570.00
	IOT 30	2508.00	2525.00	2525.67	2559.33
	IOT 40	2501.67	2513.67	2522.00	2543.00
	IOT 50	2510.67	2505.00	2517.33	2536.00

Table 3.29 Compressive strength with partial replacement of fine aggregates with iron ore tailings (IOT) and alccofine as binder (IOT-alccofine) in concrete

w/c	**Mix percentage**	**Compressive strength (MPa)**			
		3 days	**7 days**	**28 days**	**56 days**
0.35	IOT1A-0	32.00	47.33	60.33	68.00
	IOT1A-10	31.00	45.00	59.00	67.33
	IOT1A-20	34.33	45.00	61.67	69.33
	IOT1A-30	35.67	47.00	62.00	69.67
	IOT1A-40	38.00	47.67	63.00	70.00
	IOT1A-50	34.67	44.00	57.67	65.33
0.40	IOT2A-0	30.67	41.33	57.33	65.00
	IOT2A -10	30.00	41.67	57.67	65.33
	IOT2A -20	33.33	42.33	59.00	67.67
	IOT2A -30	35.00	43.67	61.33	68.67
	IOT2A -40	32.00	42.67	58.67	67.00
	IOT2A -50	30.67	40.00	55.33	62.67
0.45	IOT3A- 0	28.67	40.00	52.67	57.33
	IOT3A – 10	29.33	40.33	55.33	60.67
	IOT3A – 20	32.00	39.33	56.67	65.00
	IOT3A – 30	30.33	37.33	54.00	62.33
	IOT3A – 40	29.33	34.67	51.00	61.00
	IOT3A – 50	26.00	32.33	48.67	56.00

Table 3.30 Splitting tensile strength with partial replacement of fine aggregates with iron ore tailings (IOT) and alccofine as binder (IOT-alccofine) in concrete

w/c	**Mix proportion**	**Split tensile strength (MPa)**	
		28 days	**56 days**
0.35	IOT 0	4.21	4.25
0.35	IOT 10	4.23	4.27
0.35	IOT 20	4.34	4.59
0.35	IOT 30	4.58	4.77
0.35	IOT 40	4.79	4.86
0.35	IOT 50	4.3	4.24
0.40	IOT 0	3.96	4.16
0.40	IOT 10	4.12	4.15
0.40	IOT 20	4.25	4.48
0.40	IOT 30	4.53	4.76
0.40	IOT 40	4.1	4.24
0.40	IOT 50	3.89	4.05
0.45	IOT 0	3.84	4.12
0.45	IOT 10	4.06	4.11
0.45	IOT 20	4.2	4.36
0.45	IOT 30	4.14	4.32
0.45	IOT 40	4.03	4.2
0.45	IOT 50	3.82	4

Table 3.31 Flexural strength with partial replacement of fine aggregates with iron ore tailings (IOT) and alccofine as binder (IOT-alccofine) in concrete

w/c	Mix proportion	Flexural Strength (MPa)	
		28 days	56 days
0.35	IOT 0	6.27	6.40
	IOT 10	6.20	6.27
	IOT 20	6.33	6.60
	IOT 30	6.53	6.93
	IOT 40	6.80	7.20
	IOT 50	6.13	6.33
0.40	IOT 0	5.73	6.07
	IOT 10	5.60	6.13
	IOT 20	6.00	6.53
	IOT 30	6.47	6.73
	IOT 40	5.80	6.20
	IOT 50	5.67	5.93
0.45	IOT 0	5.60	5.87
	IOT 10	5.53	5.93
	IOT 20	5.87	6.20
	IOT 30	5.80	6.00
	IOT 40	5.47	5.80
	IOT 50	5.47	5.67

3.9.5 Optimum percentage of ıron ore waste rock and tailings (WR -IOT) - alccofine with perlite as additive in concrete

Concrete was produced with WR-alccofine and IOT-alccofine as partial replacement of natural aggregates and the optimum percentage obtained for each set of mixes is discussed in section 3.7.3 and 3.7.4. As the density of WR and IOT concrete is greater than the standard concrete mix, expanded perlite is considered as an additive. Optimum percentage of WR-alccofine and IOT-alccofine is considered and expanded perlite is partially replaced at 0%, 2.5%, 5.0%, 7.5% and 10% as fine aggregates. The workability test and mechanical properties of concrete are determined at 3, 7, 28 and 56 days for 0.35, 0.40 and 0.45 w/c. The results observed in laboratory tests are shown in Table 3.32.

(a) Workability of concrete with WR-IOT-alccofine and Perlite (P) in the production of concrete

The workability of concrete is determined as per IS 1199:1959. The slump test for concrete mixes with WR-IOT-alccofine and perlite as partial replacement of fine aggregates from 0-10% with 2.5% intervals at 3, 7, 28 and 56 curing days and w/c of 0.35, 0.40 and 0.45 was observed and presented in Table 3.32.

Table 3.32 Workability with WR-IOT-alccofine and expanded perlite (EP) in concrete

Mix percentage	**w/c**		
	0.35	**0.40**	**0.45**
	Slump (mm)		
EP-0	40	45	50
EP-2.5	35	40	45
EP-5.0	33	38	43
EP-7.5	32	35	40
EP-10.0	30	32	35

(b) Density of concrete with WR-IOT-alccofine and expanded perlite (EP) in the production of concrete

The density was determined for concrete mixes with optimum percentage of WR-IOT-alccofine and expanded perlite (EP) varying from 0-10% with 2.5% intervals at 3, 7, 28 and 56 curing days for 0.35, 0.40 and 0.45 w/c. The density values obtained are shown in Table 3.33.

Table 3.33 Density with WR-IOT-alccofine and expanded perlite (EP) in concrete

w/c	Mix	Density of WR (kg/m^3)			
		3 days	7 days	28 days	56 days
0.35	EP1-0	2616.60	2618.33	2637.00	2646.00
	EP1-2.5	2489.33	2495.33	2502.67	2506.67
	EP1-5.0	2463.00	2466.00	2472.33	2483.00
	EP1-7.5	2441.67	2445.33	2447.67	2448.67
	EP1-10.0	2378.33	2379.67	2380.00	2383.33
0.40	EP2-0	2614.00	2612.33	2631.33	2632.00
	EP2-2.5	2464.00	2500.67	2512.33	2516.67
	EP2-5.0	2459.33	2484.33	2490.33	2499.67
	EP2-7.5	2436.00	2438.33	2440.00	2442.00
	EP2-10.0	2374.00	2375.33	2377.33	2380.33
0.45	EP3-0	2609.33	2609.33	2620.23	2626.67
	EP3-2.5	2456.00	2465.00	2475.33	2483.00
	EP3-5.0	2454.00	2475.00	2480.33	2484.67
	EP3-7.5	2432.33	2428.00	2430.33	2432.00
	EP3-10.0	2369.00	2372.00	2374.33	2375.33

(c) Compressive strength of concrete with WR-IOT-alccofine and expanded perlite (EP) in the production of concrete

Compressive strength test was conducted on 100x100x100mm concrete specimens as per IS: 516-1959 with optimum percentage of WR-IOT-alccofine and varying EP from 0-10% with 2.5% interval at 3, 7, 28 and 56 days for 0.35, 0.40 and 0.45 w/c. Three trial cubes were tested for each mix proportion, curing days and w/c and the average values obtained are given in Table 3.34.

Table 3.34 Compressive strength with WR-IOT-alccofine and expanded perlite (EP) in concrete

w/c	Mix Percentage	Compressive strength (MPa)			
		3 days	7 days	28 days	56 days
0.35	EP1-0	29.00	44.33	56.33	58.33
	EP1-2.5	26.33	37.00	50.00	53.00
	EP1-5.0	27.00	38.33	52.00	55.33
	EP1-7.5	26.00	37.33	49.33	54.00
	EP1-10.0	22.00	35.00	49.00	52.00
0.40	EP2-0	27.67	40.67	53.67	57.00
	EP2-2.5	25.33	35.67	47.00	48.67
	EP2-5.0	26.00	37.00	51.33	54.00
	EP2-7.5	25.67	36.00	48.67	52.33
	EP2-10.0	24.00	34.67	47.67	50.67
0.45	EP3-0	26.33	24.67	52.67	57.33
	EP3-2.5	24.67	35.00	45.67	48.00
	EP3-5.0	25.00	36.00	51.00	53.00
	EP3-7.5	24.33	35.00	48.00	50.67
	EP3-10.0	23.67	34.00	48.00	49.00

(d) Splitting tensile strength of concrete with WR-IOT-alccofine and expanded perlite (EP) in the production of concrete

The splitting tensile strength of cylindrical concrete specimens of dimension 150x300mm were casted with optimum WR-IOT-alccofine and EP replaced as fine aggregates from 0-10% with 2.5% interval. The specimens were cured at 28 and 56 days for varying w/c of 0.35, 0.40 and 0.45 and tested as per IS 5816:1999. Three set of specimens were tested for each varying mix proportion, curing days and w/c and the average values are represented in Table 3.35.

Table 3.35 Splitting tensile strength with WR-IOT-alccofine and expanded perlite (EP) in concrete

w/c	Mix proportion	Split tensile strength (MPa)	
		28 days	56 days
0.35	EP1-0	3.92	4.01
	EP1-2.5	3.59	3.77
	EP1-5.0	3.73	3.82
	EP1-7.5	3.63	3.68
	EP1-10.0	3.54	3.59
0.40	EP2-0	3.82	3.92
	EP2-2.5	3.44	3.73
	EP2-5.0	3.59	3.87
	EP2-7.5	3.49	3.77
	EP2-10.0	3.35	3.63
0.45	EP3-0	3.68	3.87
	EP3-2.5	3.26	3.59
	EP3-5.0	3.54	3.73
	EP3-7.5	3.49	3.77
	EP3-10.0	3.26	3.59

(e) Flexural strength of concrete with WR-IOT-alccofine and expanded perlite (EP) in the production of concrete

The flexural strength of concrete beams of dimension 100x100x500mm was determined according to IS 516:1959 for the concrete mixes with optimum percentage of WR-IOT-alccofine as partial replacement of virgin aggregates and with varying percentage of EP from 0-10% with 2.5% interval at 28 and 56 days curing days for varying w/c 0.35, 0.40 and 0.45 w/c. Three trial specimens were tested for each mix composition and the average strength values are presented in Table 3.36.

Table 3.36 Flexural strength with WR-IOT-alccofine and Expanded Perlite (EP) in concrete

w/c	Mix proportion	Flexural strength (MPa)	
		28 days	56 days
0.35	EP1-0	5.53	6.07
	EP1-2.5	5.87	6.27
	EP1-5.0	6.20	6.60
	EP1-7.5	6.00	6.40
	EP1-10.0	5.87	6.33
0.40	EP2-0	5.47	5.87
	EP2-2.5	5.60	6.07
	EP2-5.0	6.13	6.47
	EP2-7.5	5.80	6.27
	EP2-10.0	5.67	6.20
0.45	EP3-0	5.33	5.47
	EP3-2.5	5.40	5.80
	EP3-5.0	5.87	6.27
	EP3-7.5	5.60	6.27
	EP3-10.0	5.40	6.00

3.10 Durability Properties by RCPT

In this section, the durability properties of WR-alccofine, IOT-alccofine and EP concrete are evaluated. Durability properties such as water absorption and rapid chloride permeability test (RCPT) are conducted and the details are discussed in this section. Table 3.37.

Table 3.37 RCPT values for concrete mixes at varying w/c and curing days

Material	Mix percentage	Charge passed (Coulombs)						Chloride ion Penetrability as per ASTM C1202
		0.35		0.4		0.45		
		28 days	**56 days**	**28 days**	**56 days**	**28 days**	**56 days**	
IOT-alccofine	IOTA-0	151	120	160	110	177	177	Very low
	IOTA-10	360	280	386	230	465	465	Very low
	IOTA-20	346	128	298	180	445	445	Very low
	IOTA-30	215	158	275	153	388	388	Very low
	IOTA-40	215	155	219	120	345	345	Very low
	IOTA-50	190	125	217	105	344	344	Very low
WR-alccofine	WRA-0	130	100	160	110	177	177	Very low
	WRA-10	146	120	159	130	169	169	Very low
	WRA-20	143	115	158	130	163	163	Very low
	WRA-30	138	110	154	120	158	158	Very low
	WRA-40	138	110	149	115	151	151	Very low
	WRA-50	133	110	144	115	149	149	Very low
EP-alccofine	EP-0	376	180	410	202	451	220	Very low
	EP-10	405	200	430	220	485	200	Very low
	EP-20	420	220	460	240	525	250	Very low
	EP-30	445	220	475	280	540	270	Very low
	EP-40	445	260	510	260	570	290	Very low
	EP-50	465	280	540	280	595	300	Very low

CHAPTER-4

CHAPTER 4

4. RESULTS OF EXPERIMENTAL INVESTIGATIONS

In this chapter, the results of experimental investigations to determine the strength and durability parameters of concrete to determine the optimum composition of material replacement are discussed. Also, regression analysis for various concrete mixes considered in the present research study is also discussed in this chapter.

4.1 Iron Ore Waste Rock (WR) as Coarse Aggregates in the Production of Concrete

M40 grade concrete consisted of OPC 53 grade, fine aggregates, coarse aggregates, water and superplasticizer. In the present case, coarse aggregates are partially replaced with Iron Ore Waste Rock (WR) from 0%, 10%, 20%, 30%, 40% and 50% and the other material composition were considered constant in the conrete mixes. The results of fresh and hardened properties of concrete for the given mix were determined at 3, 7 and 28 curing days for varying water-cement (w/c) ratio of 0.35, 0.40 and 0.45 in this section.

4.4.1 Influence of iron ore waste rock (WR) on workability of concrete

The target slump was attained as per the mix design for M40 grade for concrete with WR as coarse aggregates i.e., 25-50mm. The results are depicted in Fig. 4.1. Workability of concrete decreased with increasing percentage of WR for 0.35 w/c. Slump decreased with reference to the control mix by 8.57%, 14.29%, 20.00%, 20.00%, 28.57% for 10%, 20%, 30%, 40% and 50%, WR replaced as coarse aggregates respectively. Slump values decreased with reference to the control concrete by 7.89%, 13.16%, 21.05%, 21.05% and 26.32% with WR replaced from 10-50% for 0.40 w/c. Similarly, for 0.45 w/c, slump decreased with reference to the control mix by 7.50%, 12.50%, 20.00%, 20.00% and 25.00%. WR replaced by 10% did not show much significance but with increase in WR percentage, significant increase in workability was observed.

In comparison within the w/c, slump increased with increase in w/c from 0.35 to 0.45. Maximum slump of 50mm was attained for control mix at 0.45 w/c compared to 0.35 and 0.40 w/c.

The present work is in line with the results observed by (Binici et al. 2008) for marble and granite waste as coarse aggregate in concrete. It was observed that, it was more cohesive and workable than conventional concrete. This might be due to low water absorption and smooth surface texture of the marginal aggregates.

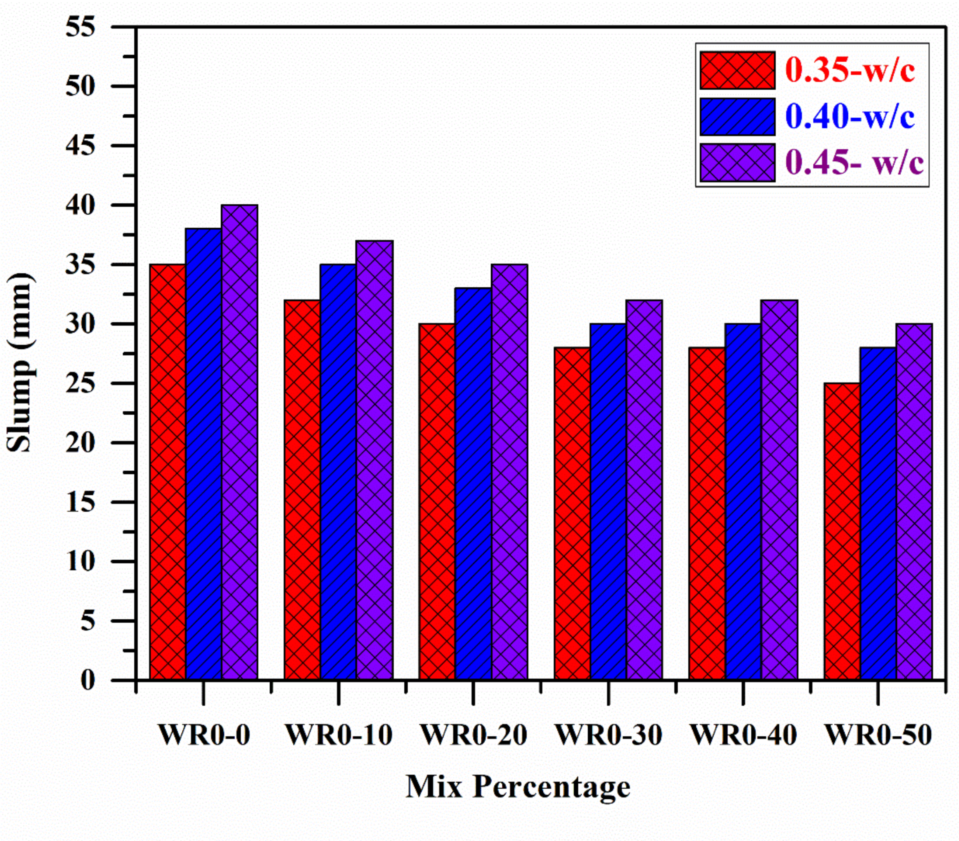


Fig. 4.1 Slump for waste rock (WR) concrete at varying w/c

4.4.2 Influence of iron ore waste rock (WR) on compressive strength of concrete

As stated in previous chapter in section 3.6.2 (a), compressive strength was carried out on 100x100x100 mm cube specimens.

At 0.35 w/c, the strength gradually increased with increased percentages of WR upto an optimum percentage of 50% (Fig. 4.2(a)). At 3, 7 and 28 curing days, maximum (optimum) strength observed with reference to the control mix concrete increased by

12.37%, 34.79% and 26.09% at WR4-40. At 0.40 w/c, with reference to the control mix, optimum strength was observed at WR5-30. Strength increased by 16.33%, 34.57% and 24.79% at 3, 7 and 28 curing days as shown in Fig. 4.2 (b). Similar increase in strength was observed at 0.45 w/c also.

In comparison within w/c, compressive strength decreased with increase in w/c from 0.35 to 0.45. The strength obtained with WR is greater than the control mix with reference to all the mixes. This increase in strength is due to the shape of the aggregates which fills the voids and thus binds the concrete and inturn increases the strength of the concrete.

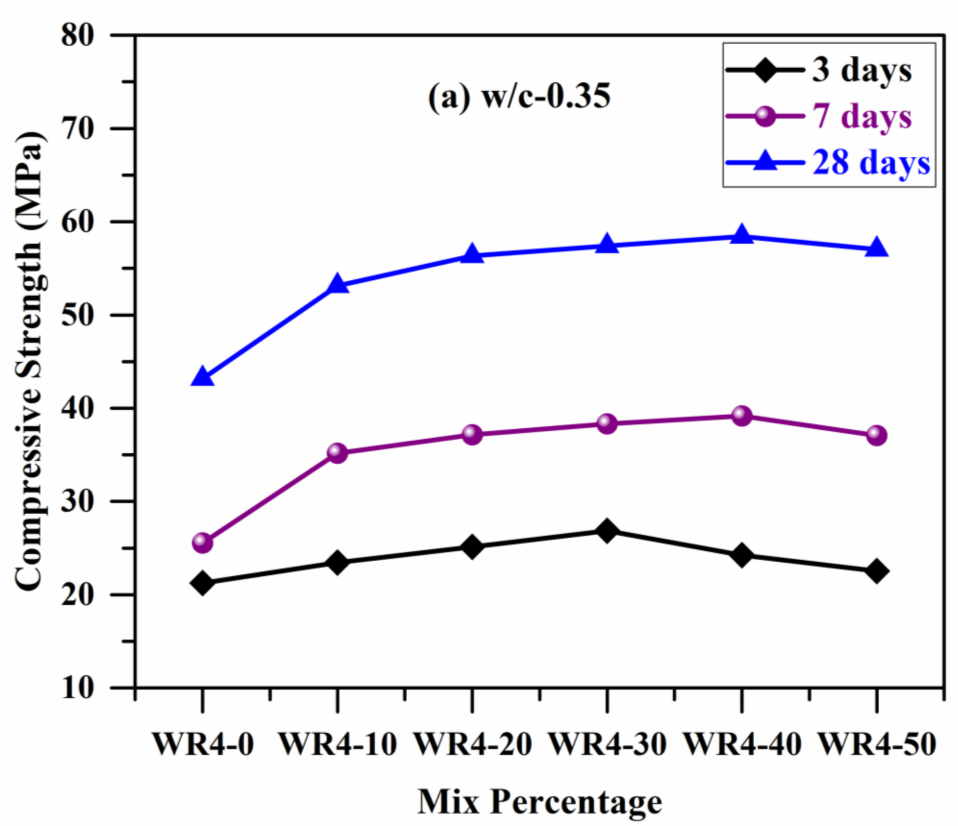


Fig.4.2(a) Compressive strength at w/c-0.35

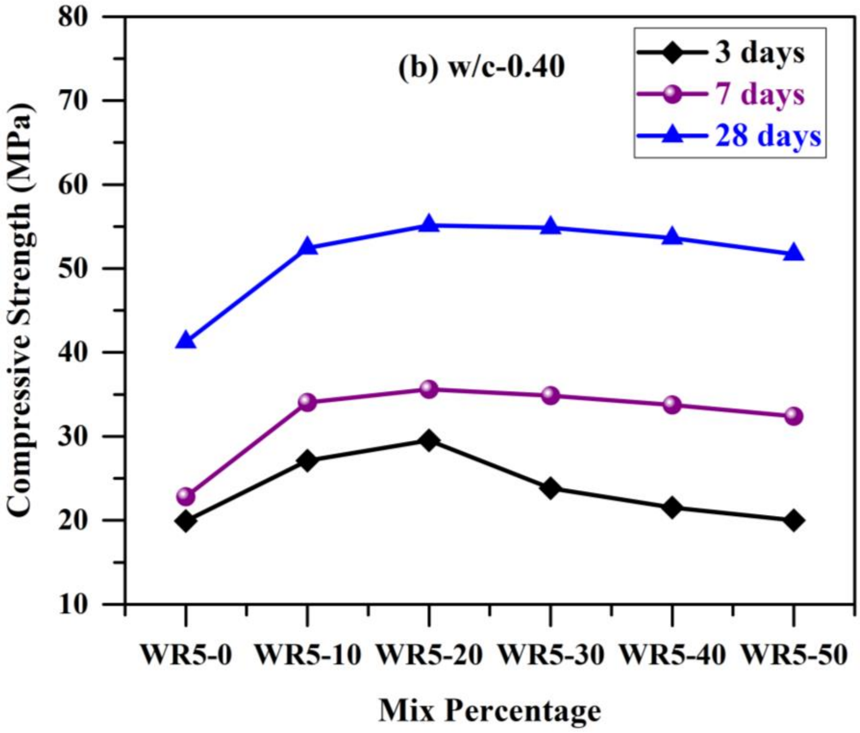


Fig. 4.2(b) Compressive strength at w/c-0.40

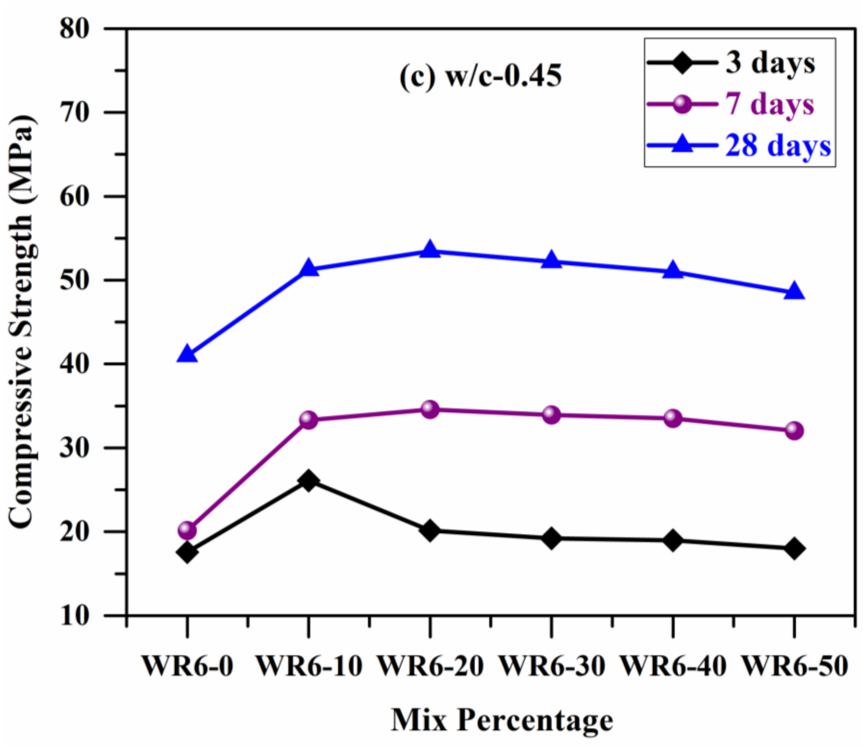


Fig.4.2(c) Compressive strength at w/c-0.45

Fig.4.2 Compressive strength for waste rock (WR) in concrete at varying w/c

4.4.3 Influence of iron ore waste rock (WR) on splitting tensile strength of concrete

Splitting tensile strength was conducted on cylindrical specimens of dimension 150x300 mm. The variation in splitting tensile strength with WR content is similar to that observed in case of compressive strength. The trend is shown in Fig. 4.3. Concrete specimens were cured for 28 days, tested and the results are illustrated in Fig. 4.3 for different w/c of 0.35, 0.40 and 0.45. For 0.35 w/c, strength of concrete specimens increased with reference to the control mix by 4.79%, 12.58%, 14.20%, 17.99% and 15.76 for WR replacement from 10-50% with 10% intervals and the optimum mix was observed at WR7-40. At 0.40 w/c, an increase in strength was observed by 5.99%, 14.15%, 16.82%, 16.04% and 14.42% with reference to the control mix for 10-50% of WR replaced concrete and the optimum mix was observed at WR7-30. Similar increasing trend was observed for 0.45 w/c and the optimum mix was observed for the mix WR7-20.

In comparison of w/c, maximum strength was obtained for mixes with 0.35 w/c and least strength was obtained at 0.45 w/c. However, the strength values are higher than the target strength required for M40 grade concrete.

4.4.4 Influence of iron ore waste rock (WR) on flexural strength of concrete

The flexural strength of concrete mixes with varying percentage of WR was determined using three point bending load as per IS standards as discussed in previous chapter in section 3.6.2 (c). Flexural strength of waste rock (WR) concrete was tested on beams of 100x100x500 mm dimension after 28 days curing and the results are depicted in Fig. 4.4.

The flexural strength increased with increase in waste rock (WR) percentage. At 0.35 w/c for 28 cured specimens, the maximum strength of 5.32 MPa was observed at 40% replacement (WR8-40). At 0.40 and 0.45 w/c, the optimum percentage replacement observed was at 30% and 20% with 5.14 and 5.13 MPa which is higher than the control mix. The flexural strength observed is greater than the target strength required (4.5MPa).

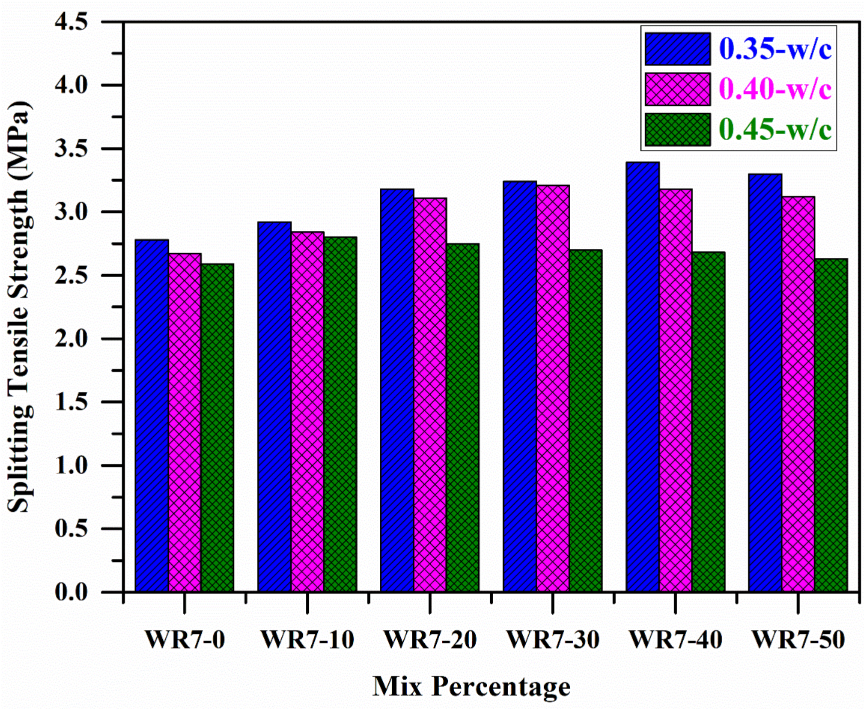


Fig. 4.3 Splitting tensile strength for waste rock (WR) concrete at varying w/c

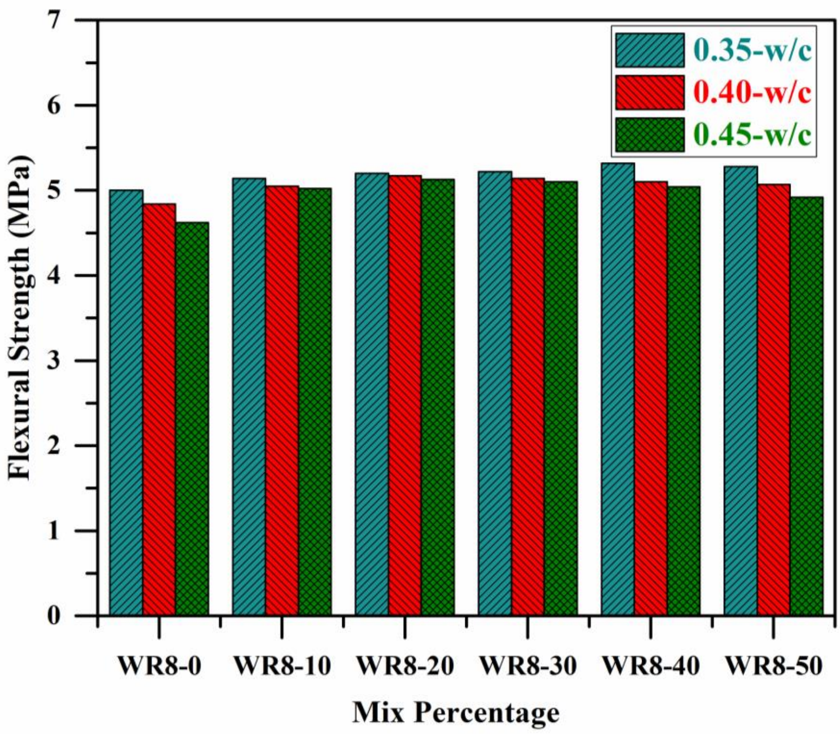


Fig.4.4 Flexural strength for waste rock (WR) concrete at varying w/c

4.2 Results of Iron Ore Tailings (IOT) as Fine Aggregates in Production of Concrete

M40 grade concrete consisted of OPC 53 grade, fine aggregates, coarse aggregates, water and superplasticizer. In the present case, fine aggregates are partially replaced with Iron Ore Tailings (IOT) from 0%, 10%, 20%, 30%, 40% and 50% and the other materials were fixed. Results of fresh and hardened properties of concrete for the given mix were determined at 3, 7 and 28 curing days for varying water-cement (w/c) ratio of 0.35, 0.40 and 0.45.

4.2.1 Influence of iron ore tailings (IOT) on workability of concrete

Conrete fresh mix was tested for workability with partial replacement of IOT in laboratory. With reference to the control mix, decrease in workability was observed with increase in IOT from IOT3-0 to IOT3-50 as illustrated in Fıg. 4.7.

Slump values were maximum for control mix concrete and gradually decreased with increase in IOT percentage and very low workability was observed with 50% replacement of IOT.

With reference to results within w/c, an increase in workability was observed with increase in w/c i.e., from 0.35 to 0.40. Slump values were on higher range from 25-35 mm compared to other w/c. This decrease in workability is due to the high surface area of iron ore mine tailings. The desired slump value as per the mix design for M40 grade concrete is 25-50 mm. The concrete is workable upto 40% replacement of IOT, thereafter the mix becomes rigid due to high water absorption of IOT.

4.2.2 Influence of iron ore tailings (IOT) on compressive strength of concrete

Compressive strength of concrete was determined for varying percentages of IOT i.e., 0%, 10%, 20%, 30%, 40% and 50% at 3, 7 and 28 curing days for varying w/c of 0.35, 0.40 and 0.45.

Compressive strength shows an increasing trend in strength with reference to 3, 7 and 28 days cured specimens. Results at 0.35 w/c for 3 days cured specimens with reference to control mix concrete, strength increased by 15.51%, 27.00%, 37.07%, 19.87% , for 7 days cured specimens, strength increased by 10.54%, 24.52%, 31.56%, 9.46%, 6.51% and for 28 days cured specimens, strength increased by 10.88%, 14.39%, 17.14%, 8.19% and 2.02% at 10%, 20%, 30%, 40% and 50% IOT replacement respectively. Maximum strength of 52.11 MPa was observed for 28 cured specimens and the optimum percentage obtained was at 30% IOT replacement sas illustrated in Fig. 4.6(a).

Similar trends were observed for 28 days cured specimens at 0.40 and 0.45 w/c. Maximum strength of 44.85 MPa and 43.15 MPa was observed at optimum IOT percentage of 20% and 10% respectively as illustrated in Fig. 4.6(b) and 4.6(c).

In comparison withing the w/c, the strength reduction was observed from 0.35 to 0.45 w/c due to the increased surface area of concrete with the increasing percentage of iron ore tailings (IOT), which in turn increases the demand of water and decreases the strength of concrete.

4.2.3 Influence of iron ore tailings (IOT) on splitting tensile strength concrete

Splitting tensile strength was tested on 28 days cured concrete specimens of dimension 150x300 mm as per IS standards. Strength with reference to the control mix concrete was found to be at 0%, 10%, 20%, 30%, 40% amd 50% IOT replacement respecitively were 2.78 MPa, 3.74 MPa, 3.82 MPa, 3.91 MPa, 3.86 MPa and 3.84 MPa at 0.35 w/c; 2.67 MPa, 3.62 MPa, 3.71 MPa, 3.68 MPa, 3.62 MPa and 3.58 MPa at 0.40 w/c and 2.59 MPa, 3.554 MPa, 3.51 MPa, 3.47 MPa, 3.42 MPa and 3.38 MPa at 0.45 w/c. Maximum strength was observed at 30%, 20% and 10% of IOT replacement for 0.35, 0.40 and 0.45 w/c.

In comparison within w/c, splitting tensile strength gradually decreased with increase in w/c from 0.35 to 0.45. Strength obtained from control mix was in the range of 2.59-2.78 MPa and maximum strength was in the range of 3.54-3.91 MPa.

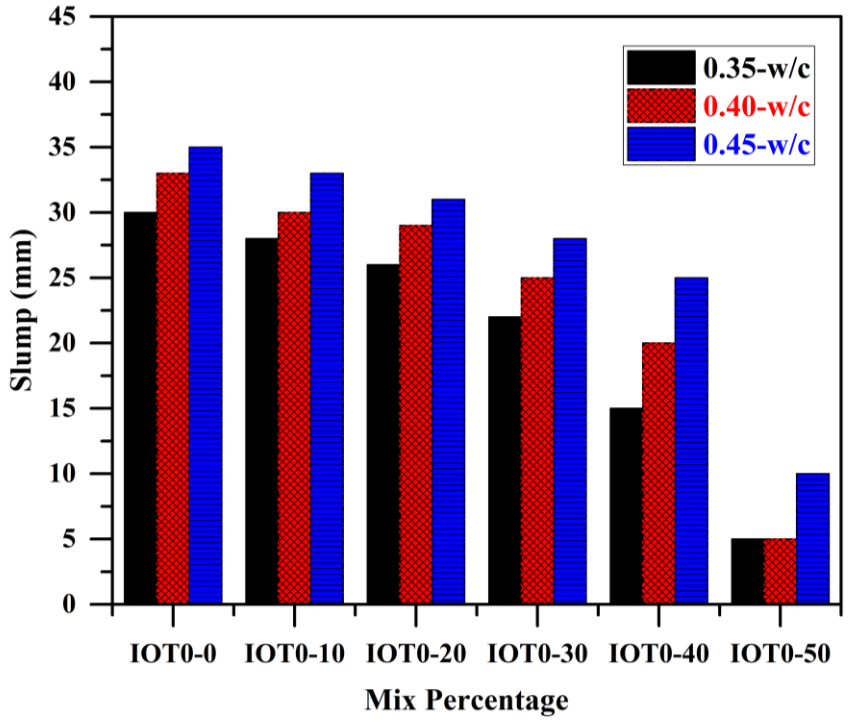


Fig.4.5 Slump values of iron ore tailings (IOT) concrete at varying w/c

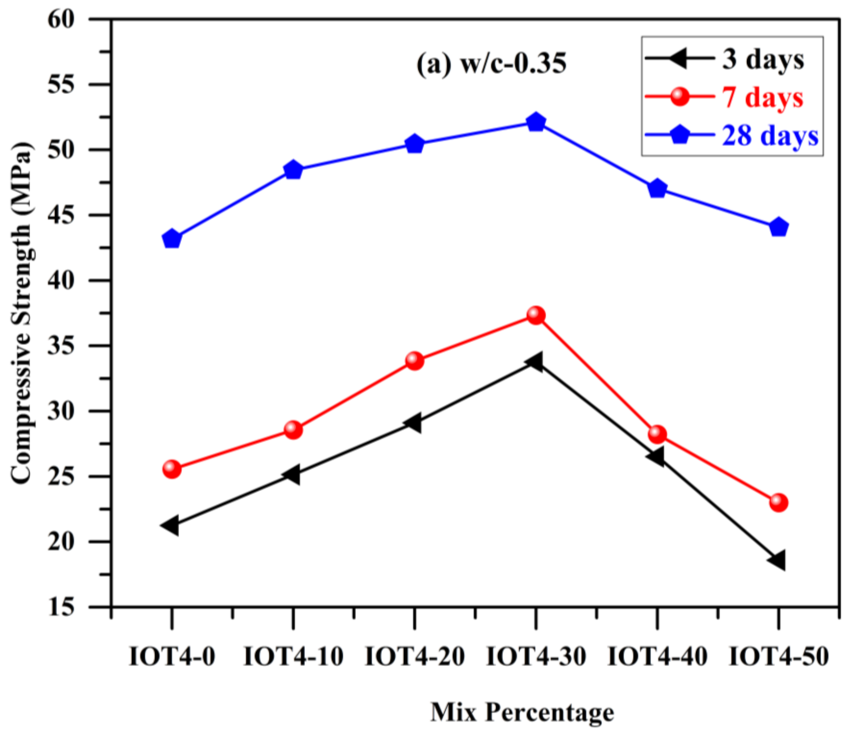


Fig.4.6 (a) Compressive strength for w/c - 0.35

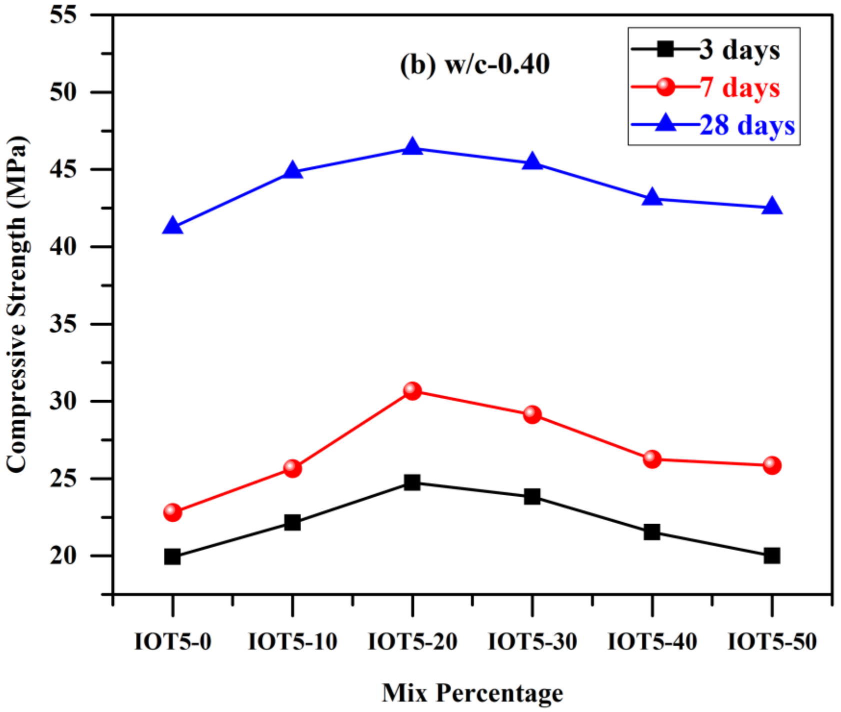


Fig.4.6 (b) Compressive strength for w/c-0.40

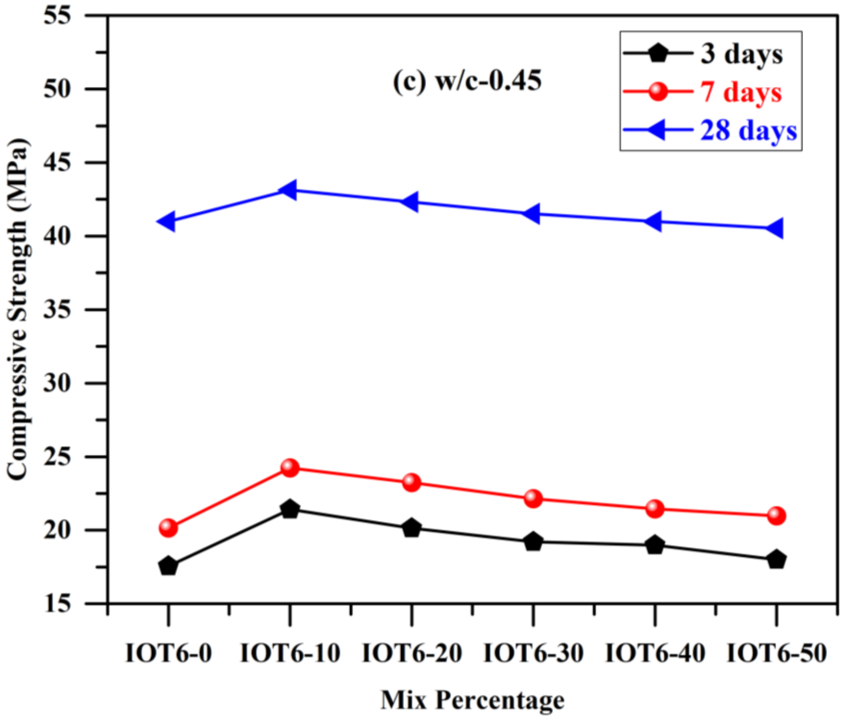


Fig.4.6 (c) Compressive strength for w/c - 0.45

Fig. 4.6 Compressive strength for iron ore tailings (IOT) concrete for varying w/c and curing days

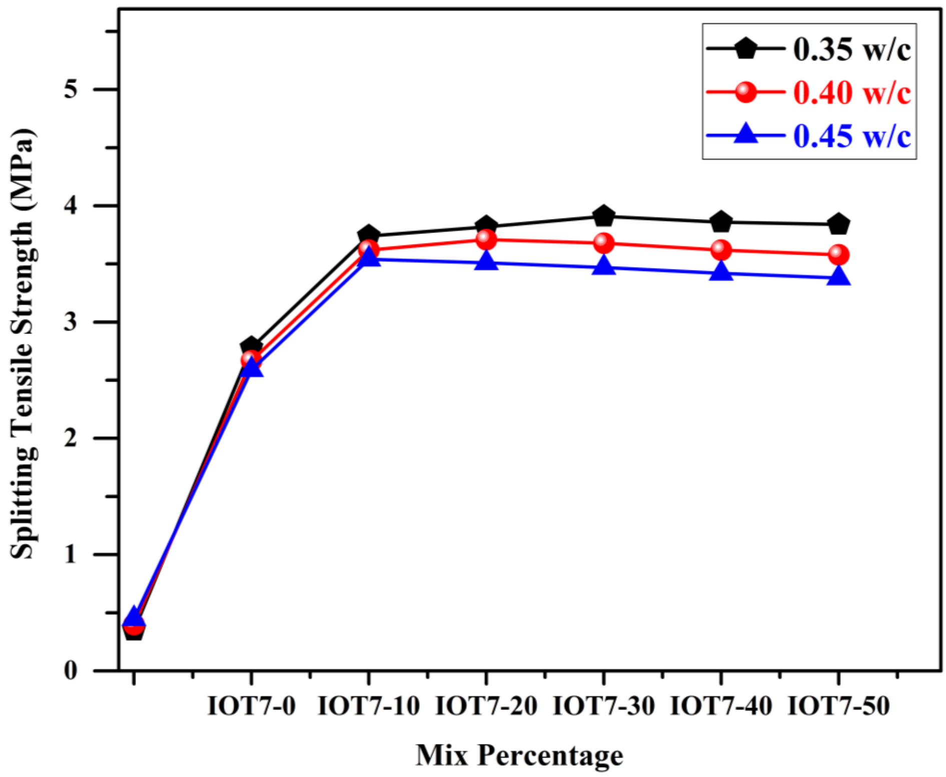


Fig. 4.7 Splitting tensile strength for iron ore tailings (IOT) for varying w/c

4.2.4 Influence of iron ore tailings (IOT) on flexural strength of concrete

Flexural strength of all the concrete specimens with IOT was determined on concrete beams for 28 cured specimens using three point bending load as per IS standards. The results are depicted in Fig. 4.8.

Flexural strength increased with increase in IOT replacement from 10% - 50% with 10% interval. At 0.35 w/c, strength increased with reference to control mix concrete by 4.40%, 5.12%, 4.03%, 3.47% and 5.12%. At 0.40 w/c, with reference to the control mix strength increased by 6.74%, 7.10%. 6.02%, 4.72% and 3.39%. Similarly, at 0.45 w/c, strength increased by 9.41%, 7.97%, 6.29%, 4.55% and 2.94% was with reference to control mix. Optimum percentage was observed at 30%, 20% and 10% IOT replacement for 0.35, 0.40 and 0.45 w/c. The flexural strength observed is greater than the required target strength of 4.5MPa.

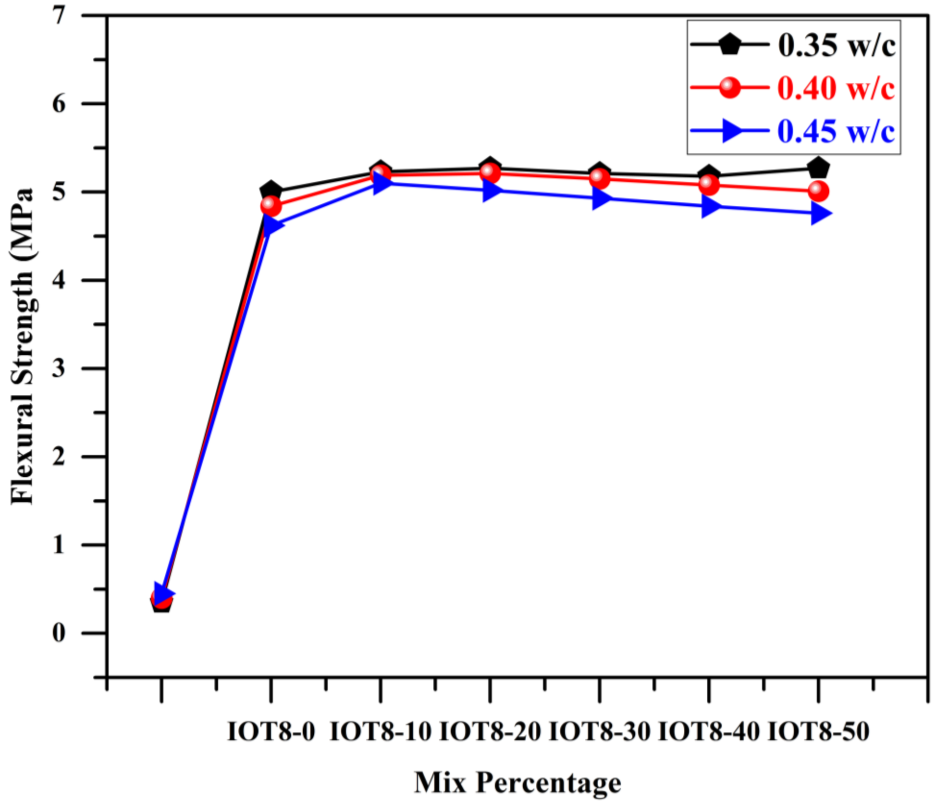


Fig. 4.8 Flexural strength of iron ore tailings (IOT) concrete for varying w/c

4.3 Iron Ore Waste Rock (WR) – Alccofine in Production of Concrete

Iron ore waste rock (WR) is partially replaced as coarse aggregates in concrete and the results are illustrated in section 4.2. The mechanical properties were tested for specimens cured for 3, 7 and 28 days. To further enhance these properties of WR concrete, admixture is added. Alccofine, a micro fine particle is used as an admixture is partially replaced with cement at 10% for the varying percentage of WR of 0%, 10%, 20%, 30%, 40% and 50% for 3, 7, 28 and 56 days curing and at varying w/c of 0.35, 0.40 and 0.45. Concrete specimens are tested for 56 days also as the cementitious material is replaced with admixtures which might show strength variations at higher curing days.

4.3.1 Influence of WR-alccofine on workability of concrete

Concrete is designed for M40 grade concrete. The required slump values are 25-50 mm. Workability of fresh concrete is determined for WR and alccofine as aggregate and cement replacement respectively using a slump cone. With reference to the slump test, workability of concrete increased with increase in WR replacement as coarse aggregates and in comparison within w/c, workability increased with increase in w/c from 0.35 to 0.45. With increase in WR upto 50% and with 10% alccofine as cementitious material, a gradual decrease in strength was observed. On an average, the workability was good for WR-alccofine mixes obtained in the range of 35-50 mm slump (Fig. 4.9).

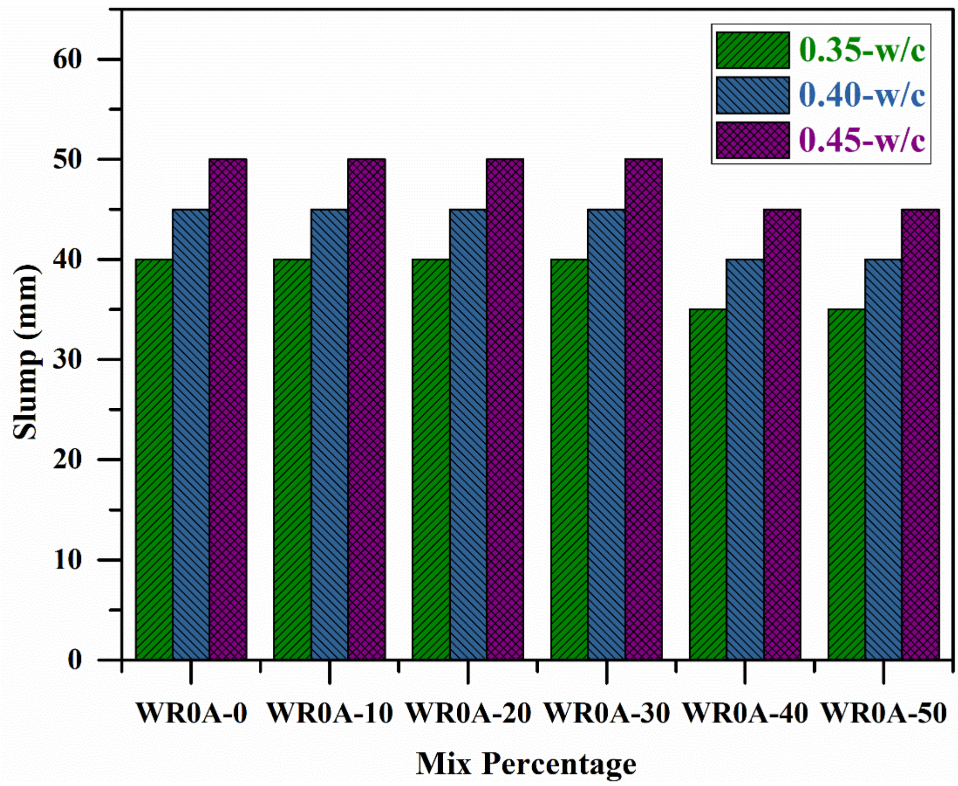


Fig. 4.9 Slump trend of waste rock (WR)-alccofine concrete for varying w/c

4.3.2 Influence of WR-alccofine on density of concrete

Density of WR-alccofine concrete mixes with different mix proportions at varying w/c was determined at 3, 7, 28 and 56 curing days.

Density observed for varying curing days at 0.35 w/c is illustrated in Fig. 4.10(a). Density increased with increase in addition of WR-alccofine in concrete. For 3 days cured specimens density increased by 0%, 2.46%, 3.56%, 3.54%, 3.71%; for 7 days cured specimens density increased by 0%, 3.44%, 3.81%, 3.59% and 5.11%; for 28 days cured specimens density increased by 1.01%, 4.96%, 5.10%, 3.72% and 5.43% and for 56 days cured concrete specimens, density increased by 0%, 3.46%, 3.57%, 2.19% and 3.71% with reference to control mix (0% WR-alccofine replacement) for 10%, 20%, 30%, 40% and 50% WR-alccofine replacement respectively.

Density for concrete specimens with 0.40 and 0.45 w/c at varying curing days of 3, 7, 28 and 56 days depicted similar increase in density as in the case of 0.35 w/c. Density was greater at 28 and 56 days cured concrete specimens as illustrated in Fig. 4.10(b) and 4.10(c).

In comparison within w/c of 0.35, 0.40 and 0.45, density decreased with increase in w/c. For 56 days cured specimens at 50% WR-alccofine replacement, maximum density is 2694.33 Kg/m^3 at 0.35 w/c compared to 0.40 and 0.45 w/c concrete specimens with 2654.00 Kg/m^3 and 2639.00 Kg/m^3 respectively.

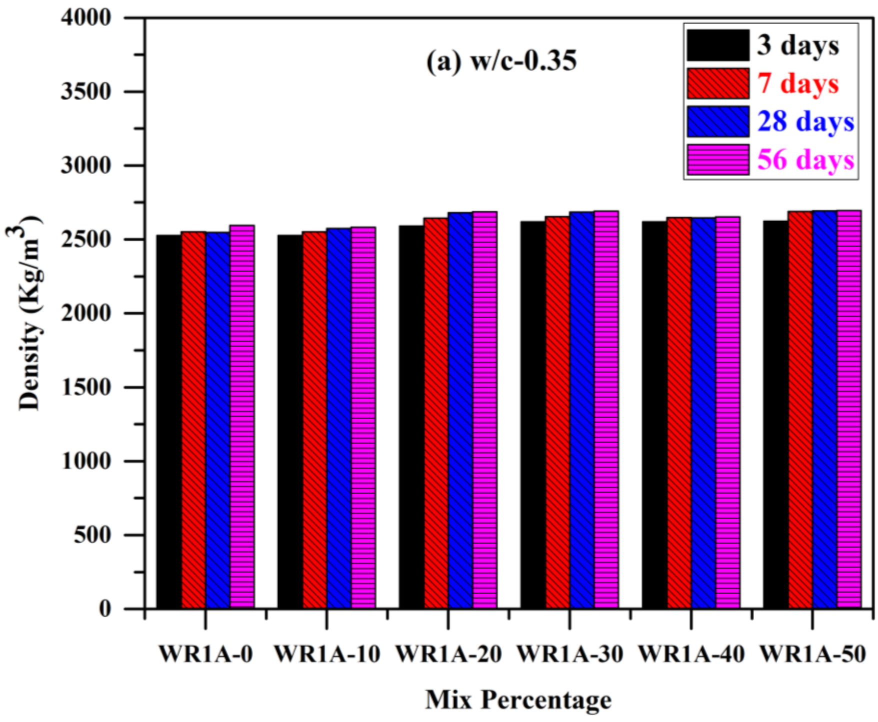


Fig. 4.10(a) Density for w/c-0.35

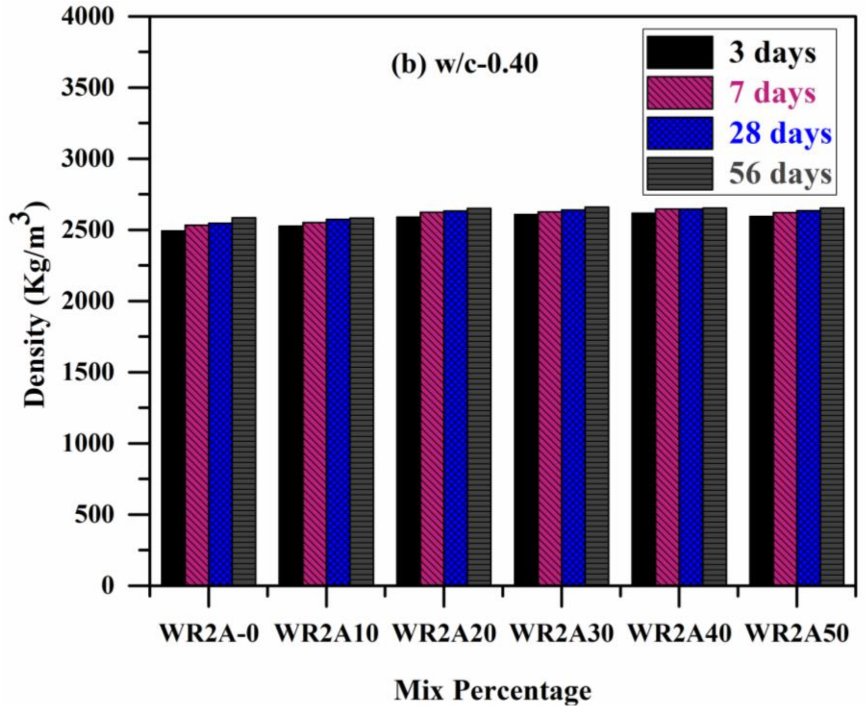


Fig. 4.10(b) Density for w/c- 0.40

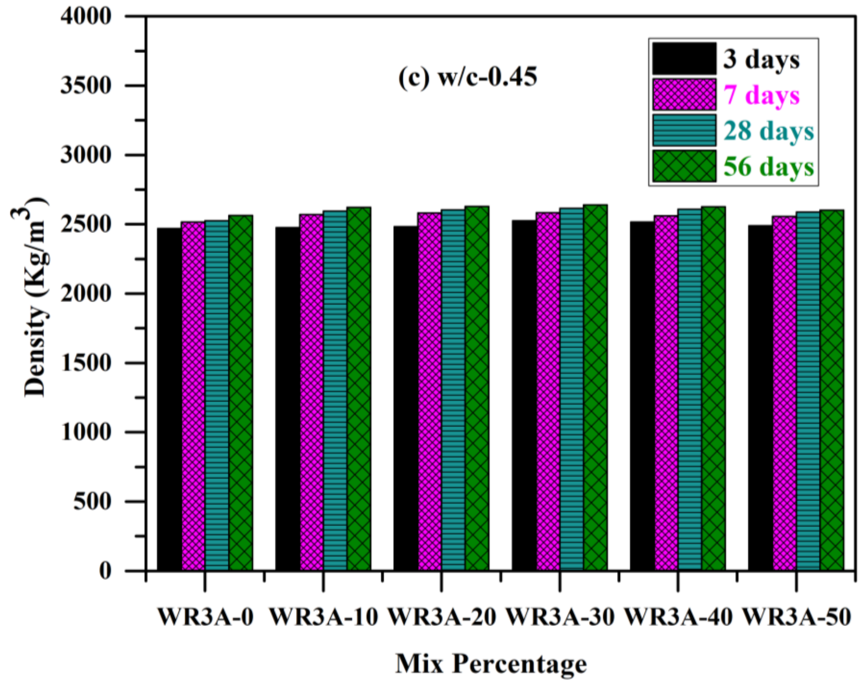


Fig. 4.10(c) Density for w/c 0.45

Fig. 4.10 Density of waste rock (WR)-alccofine concrete at varying w/c

4.3.3 Influence of WR-alccofine on compressive strength of concrete

Compressive strength of concrete specimens of dimension 100x100x100 mm were tested for varying WR-alccofine mix proportions from 0% to 50% with 10% interval for 3, 7, 28 and 56 cured specimens at 0.35, 0.40 and 0.45 w/c.

Compressive strength at 0.35 w/c for WR-alccofine replacement by 10%, 20%, 30%, 40% and 50% with refernece to control mix concrete for 3 days cured specimens increased by 11.93%, 29.93%, 33.33%, 37.25% and 39.62%; for 7 days cured specimens strength increased by 1.39%, 4.05%, 12.35%, 15.48% and 16.96%; for 28 cured specimens strength increased by 0.55%, 1.09%, 5.73%, 8.59% and 11.27% and for 56 days cured specimens strength increased by 0.49%, 4.23%, 6.85% and 9.73% respectively. Maximum strength was observed at 28 and 56 days cured specimens, optimum mix percentage for 0.35 w/c was observed at 50% WR-alccofine replacement.

Compressive strength for 3, 7, 28 and 56 days cured specimens were tested for varying mix proportion of WR-alccofine replacement at 0.40 w/c and 0.45 w/c. Strength increased by 10.88% and 9.72% at 0.40 w/c and 10.34% and 5.91% at 0.45 w/c respectively for concrete specimens cured at 28 and 56 days at optimum percentage of 40% and 30% WR-alccofine replacement respectively. Strength increased upto the optimum percentages and then decreased gradually. Fig. 4.11 (a), Fig. 4.11 (a), Fig. 4.11 (a) are shown for WR-alccofine concrete for 0.35, 0.40 and 0.45 w/c. below.

The C_3S, C_2S and C_4AF present in foundry slag (FD) facilitated in refining the mechanical properties of concrete by (Thiery et al. 2005). The high content of SiO_2 in FD had reacted with $Ca(OH)_2$ and had produced additional C-S-H gel which helped in improving the CS at later ages as explained by (Zhang et al. 2011). (Chávez-Ulloa et al. 2013) observed that free chloride ions in concrete affect the strength properties of concrete.

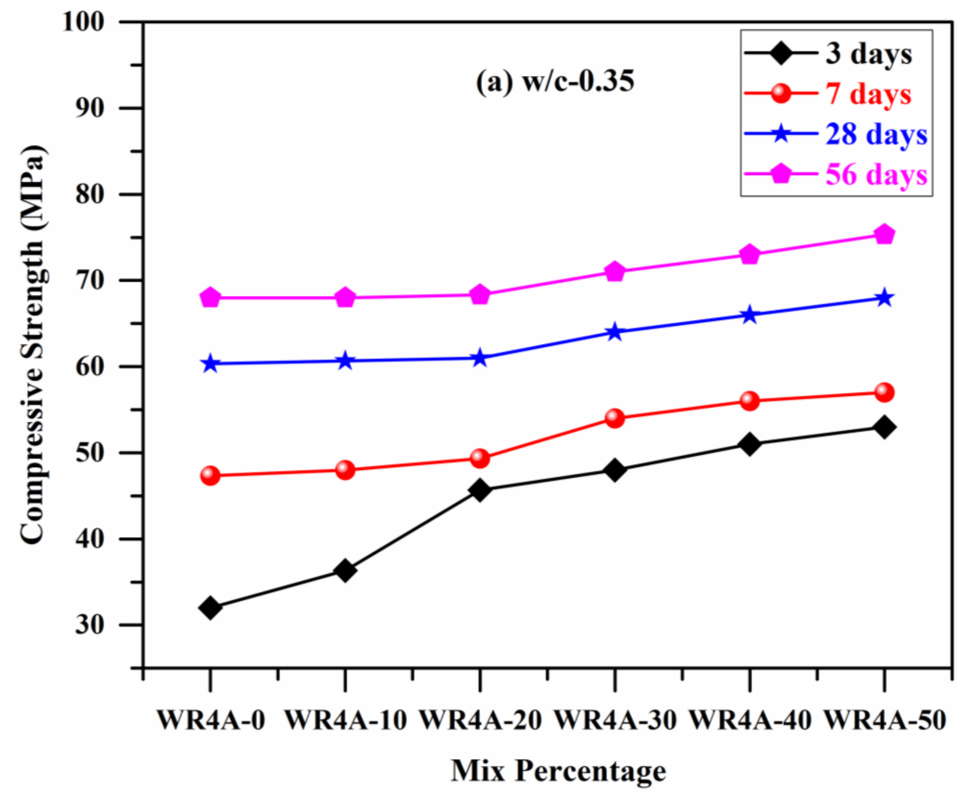


Fig. 4.11(a) Compressive strength for w/c 0.35

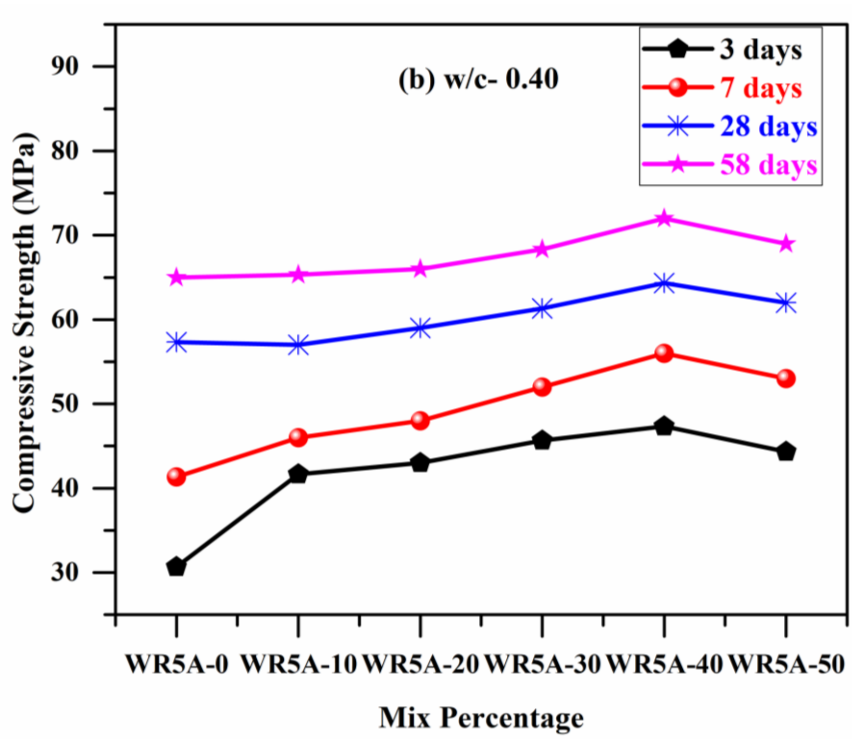


Fig. 4.11(b) Compressive strength for w/c 0.40

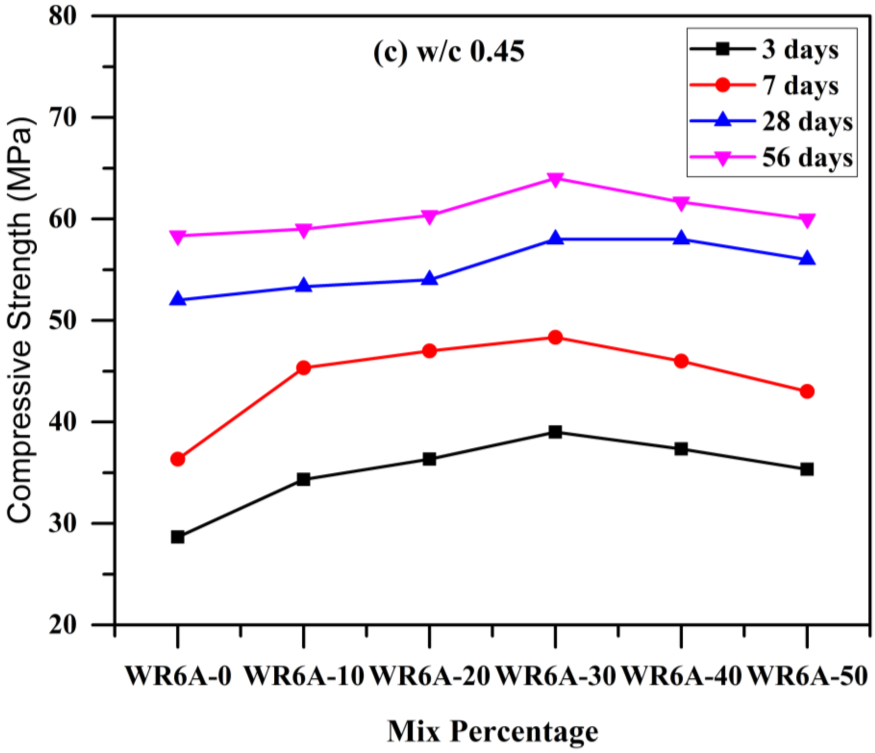


Fig. 4.11(c) Compressive strength for w/c 0.45

Fig. 4.11 Compressive strength for waste rock (WR) -alccofine for varying w/c

4.3.4 Influence of WR-alccofine on splitting tensile strength of concrete

Splitting tensile strength test assess a material's capacity to resist a diametric compressive force, and were carried out in a compression testing machine with rate of loading 1.2- 2.4 MPa/min for cylindrical specimens of dimension of 150x300 mm. These specimens were cured for 28 and 56 days at 0.35, 0.40 and 0.45 w/c.

With reference to the control mix concrete for 28 and 56 cured specimens, strength was enhanced by 2.27%, 4.55%, 7.95%, 9.09%, 7.95% and 3.26%, 6.52%, 11.96%, 16.30% for WR-alccofine replacement at 10%, 20%, 30%, 40% and 50% respectively at 0.35 w/c as illustrated in Fig. 4.12(a). Optimum mix percentage obtained at 50% WR-alccofine replacement.

Similarly, splitting tensile strength for 28 and 56 days cured concrete speciments with varying percentage of WR-alccofine from 10-50% at 0.40 and 0.45 w/c depicted similar trend as in 0.35 w/c. But in this case, the optimum percentage was obtained at

40% and 30% WR-alccofine replacement for 0.40 and 0.45 w/c respectively as illustrated in Fig. 4.12(b) and 4.12(c).

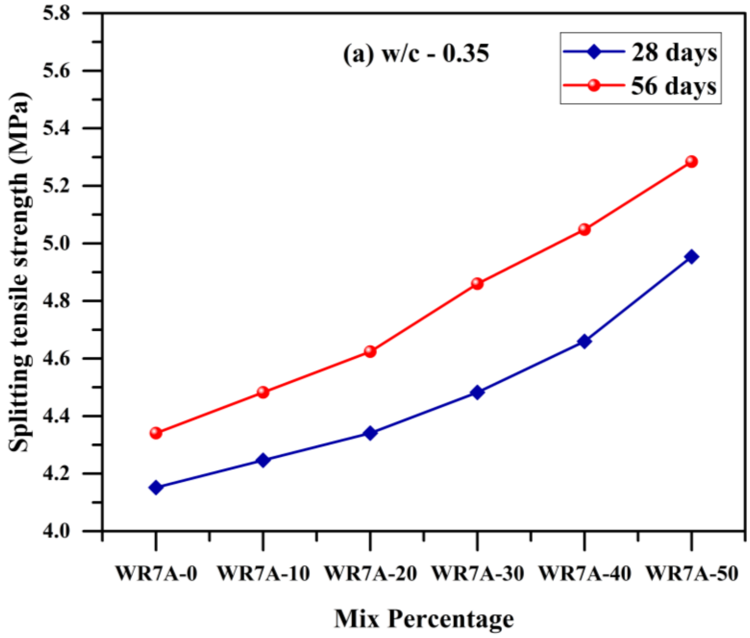


Fig. 4.12(a) Splitting tensile strength for w/c-0.35

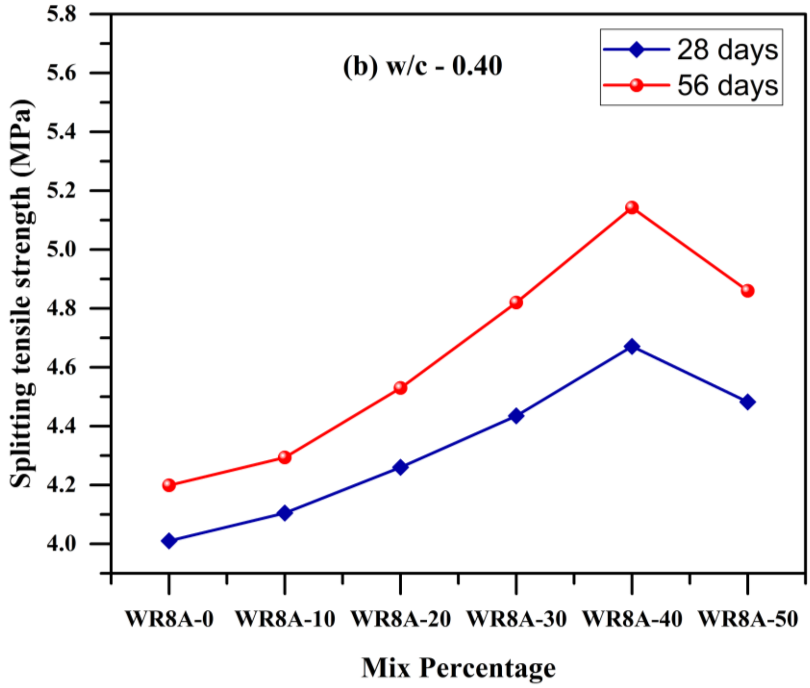


Fig. 4.12(b) Splitting tensile strength for w/c-0.40

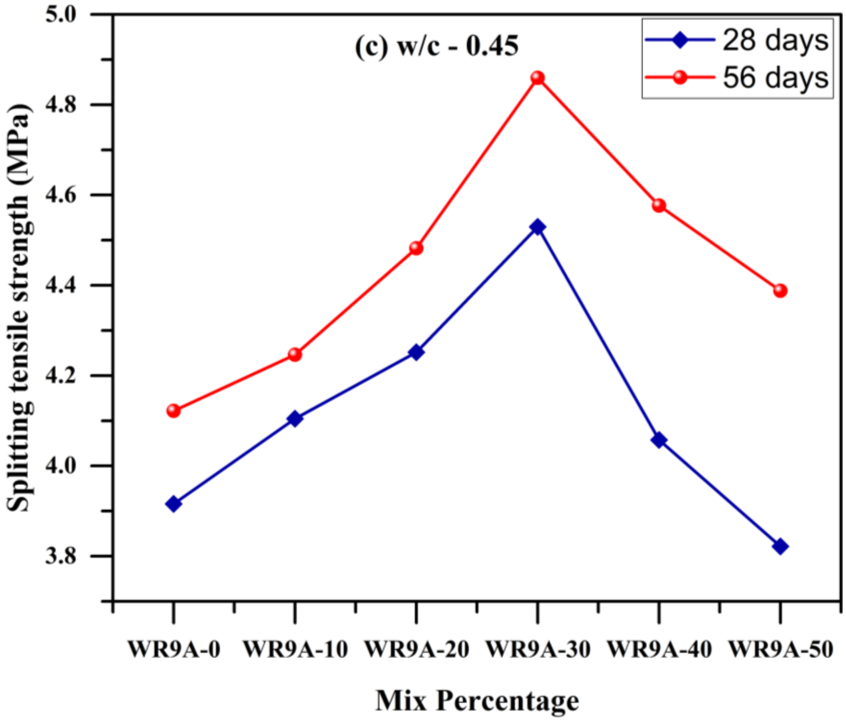


Fig. 4.12(c) Splitting tensile strength for w/c- 0.45

Fig. 4.12 Splitting tensile strength of waste rock (WR) -alccofine concrete at varying w/c

4.3.5 Influence of WR-alccofine on flexural strength of concrete

Three-point bending tests were carried out to analyse the behavior of WR-alccofine concrete in flexure. Concrete beams with WR-alccofine were tested at 28 and 56 days curing for varying w/c of 0.35, 0.40 and 0.45. With reference to the control mix concrete, flexural strength was enhanced by 10% and 19% at 28 and 56 cured days respectively at 0.35 w/c for 50% WR-alccofine replacement as illustrated in Fig. 4.13(a). At 0.40 w/c and 0.45 w/c strength was enhanced by 15% and 20%; 12 and 13% at 28 and 56 curing days respectively and optimum percentage was obtained at 40% and 30% WR-alccofine replacement as illustrated in Fig. 4.13(b) and 4.13(c).

Increase in compressive strength is due to angular aggregates, better toughness and hardness properties of WR aggregates which ensure strong bonding and adhesion between WR aggregates and cement/alccofine paste.

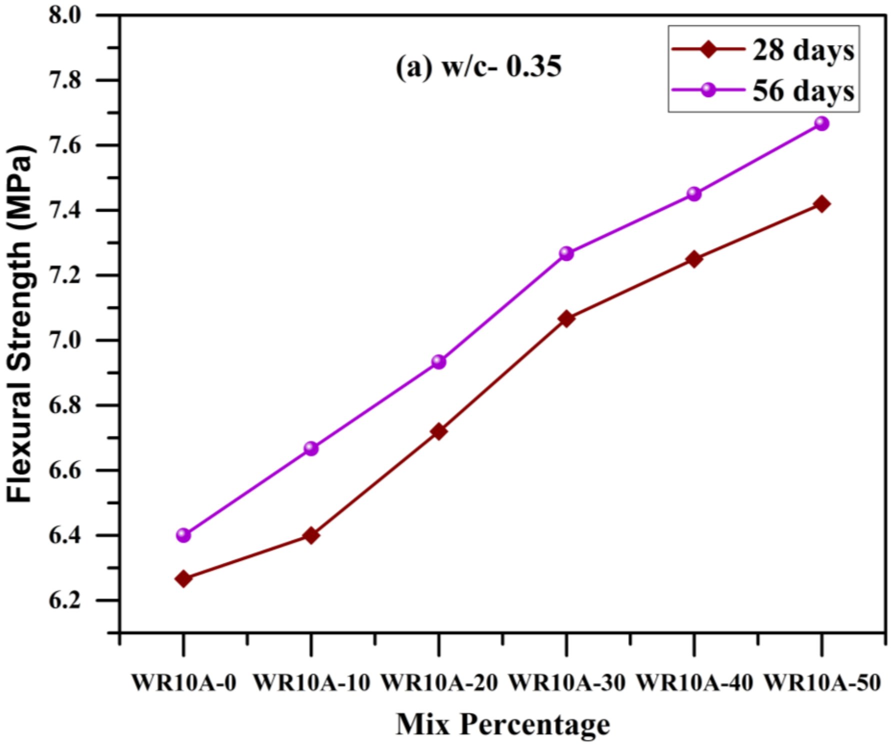


Fig. 4.13(a) Flexural strength for w/c-0.35

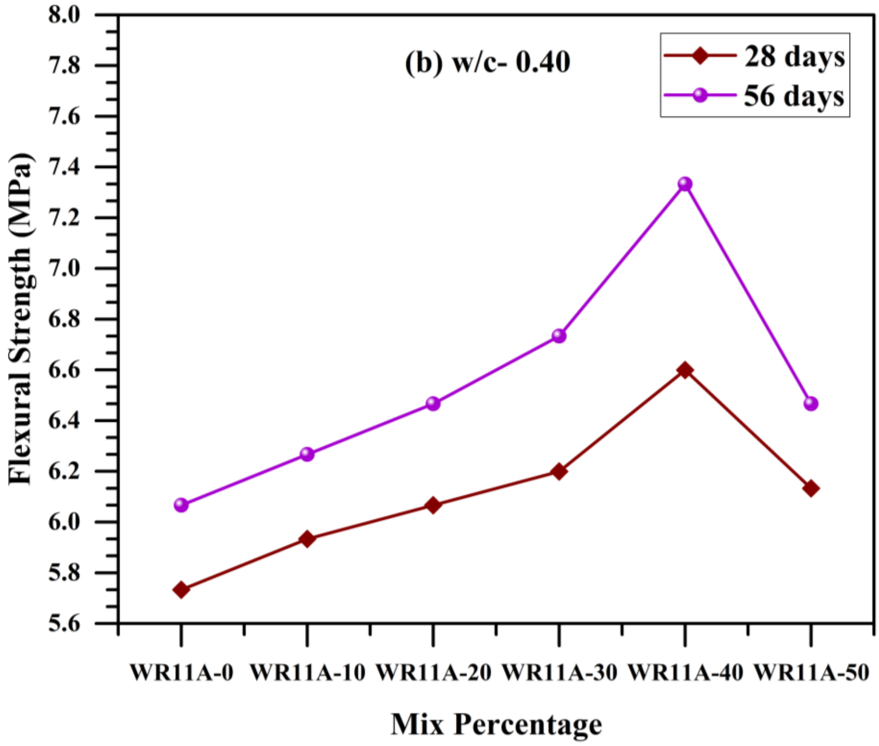


Fig. 4.13(b) Flexural strength for w/c-0.40

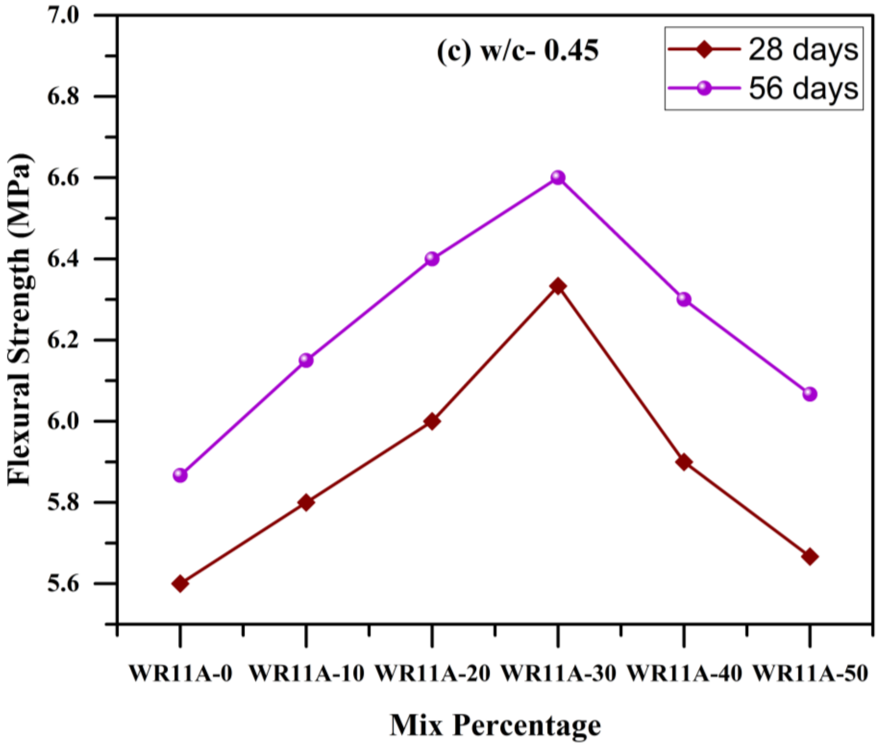


Fig. 4.13(c) Flexural strength for w/c-0.45

Fig. 4.13 Flexural strength for waste rock (WR) -alccofine concrete at varying w/c

4.4 Results of IOT-Alccofine in Production of Concrete

Iron ore tailings (IOT) partially replaced as fine aggregates and the results are discussed in section 4.2. To further enhance these properties of IOT concrete, alccofine is used as an admixture and is partially replaced with cement by 10% for varying percentage of İOT by 0%, 10%, 20%, 30%, 40% and 50% keeping other material compositions constant and tested for 3, 7, 28 and 56 days curing at varying w/c of 0.35, 0.40 and 0.45.

4.4.1 Influence of IOT-alccofine on workability of concrete

Influence of IOT-alccofine on workability of concrete was measured using slump cone. With increase in IOT replacement upto 50% and with 10% alccofine as cementitious material, a decrease in 38%, 27% and 26% was observed for mixes compared to control mix concrete for 0.35, 0.40 and 0.45 w/c respectively.

With reference to the results obtained, by increasing the IOT-alccofine in concrete, workability of concrete decreased. With increase in w/c ratio from 0.35, 0.40 and 0.45, workability of IOT-alccofine concrete increased. This might be due to the high water absorption, angular surface area and fineness of IOT materials. The fineness modulus of IOT is 3.05 due to which, the water demand increases, thus resulting in decrease in workability.

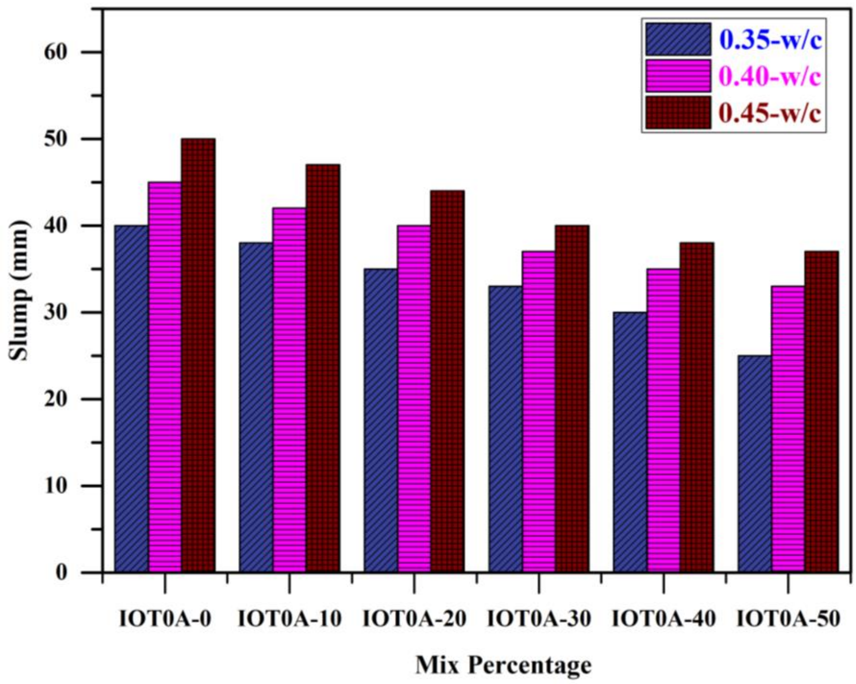


Fig. 4.14 Slump values for iron ore tailings (IOT) -alccofine concrete at varying w/c

4.4.2 Influence of IOT-alccofine on density of concrete

Density of concrete with varying IOT-alccofine proportions at varying w/c at 3, 7, 28 and 56 cured days were determined on hardened concrete cubes of dimension 100mm*100mm*100mm. The density observed was almost equal to or slightly varied with increase in IOT-alccofine replacement with reference to the control concrete. The density ranged between 2,535 to 2,690 Kg/m^3 for all the mix proportions. This increase in density might be due to the high specific gravity of IOT. The densities of different mix proportions are plotted in Figs. 4.15. As shown Fig. 4.15(a) density increased with increase in curing days for w/c 0.35 and similar trend is observed for 0.40 and 0.45 w/c as shown in Fig. 4.15(b) and Fig. 4.15(c).

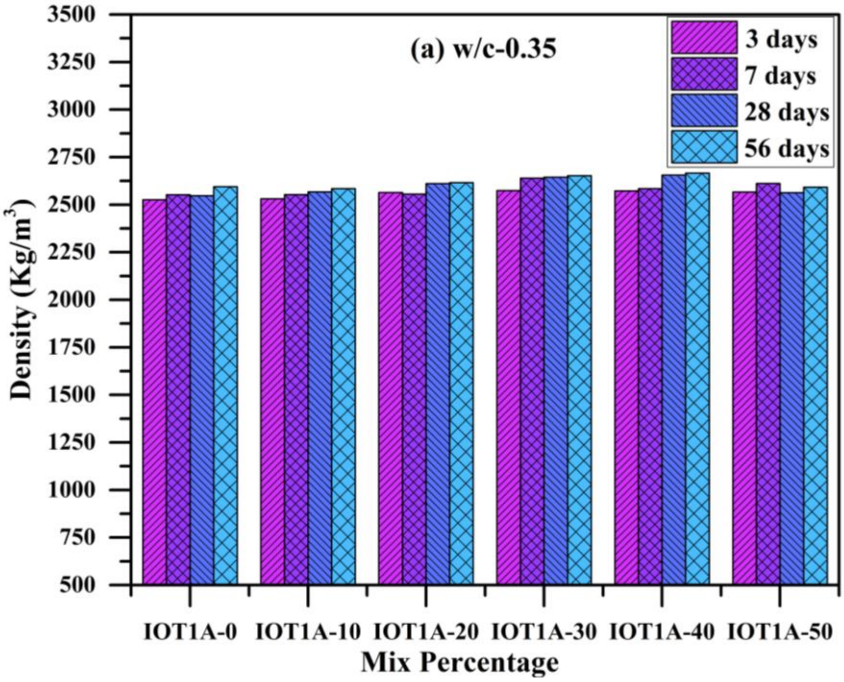


Fig. 4.15 (a) Density for w/c-0.35

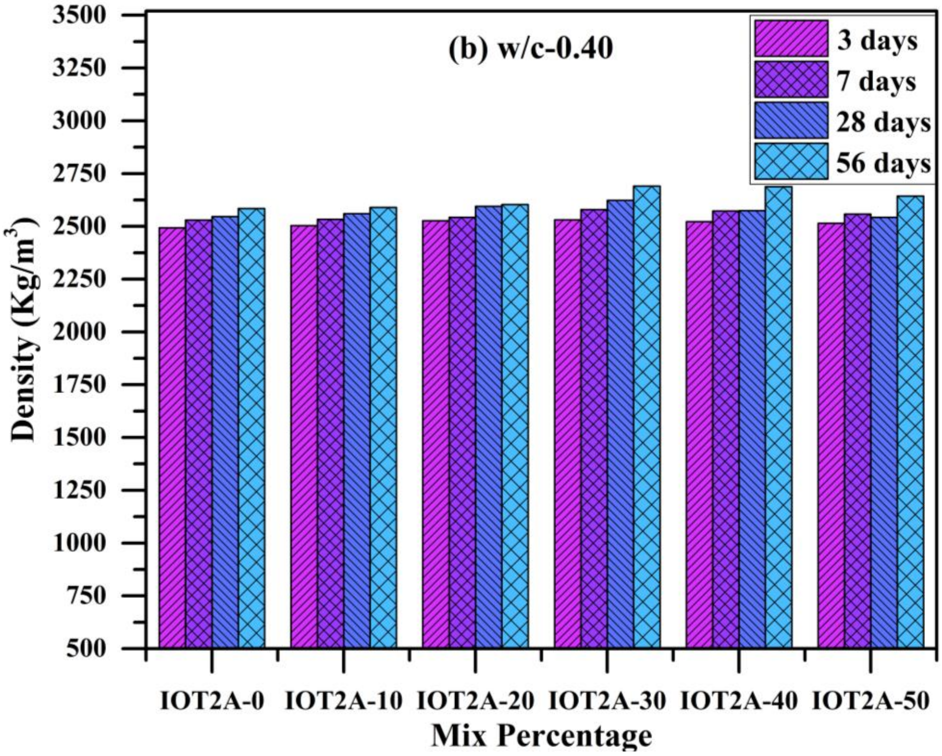


Fig. 4.15 (b) Density for w/c-0.40

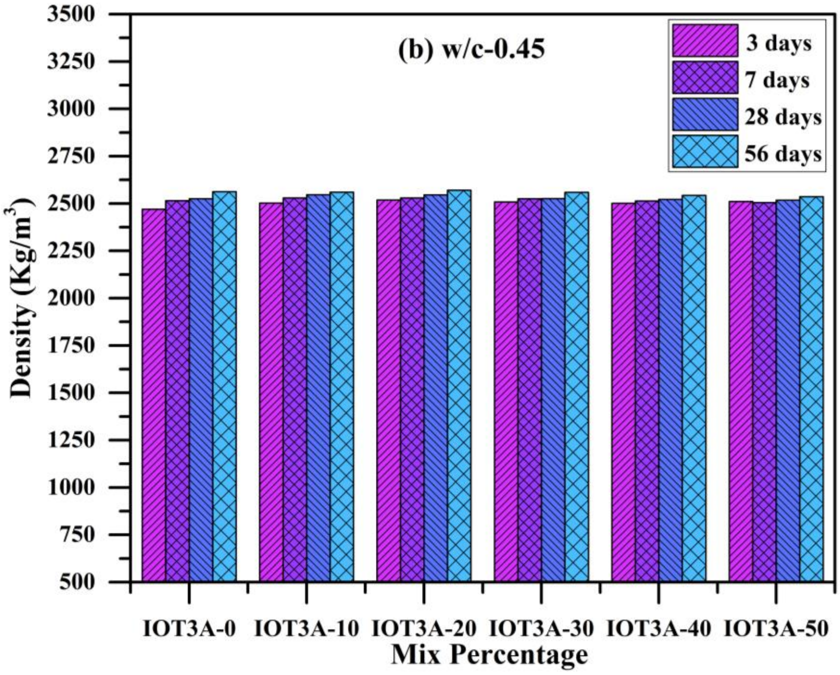
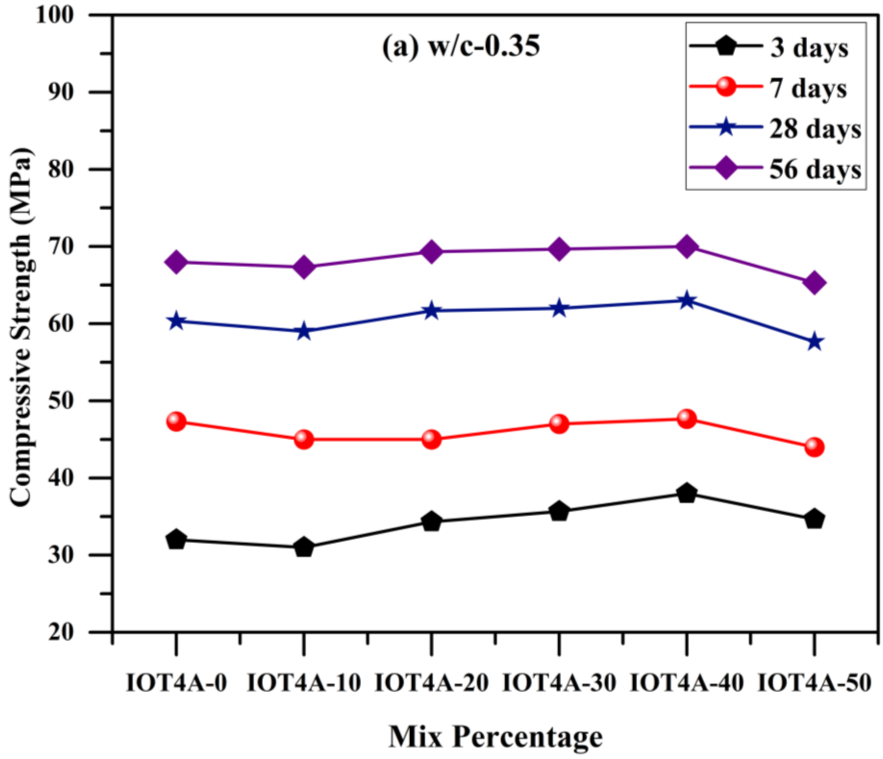


Fıg. 4.15 (c) Density for w/c-0.45

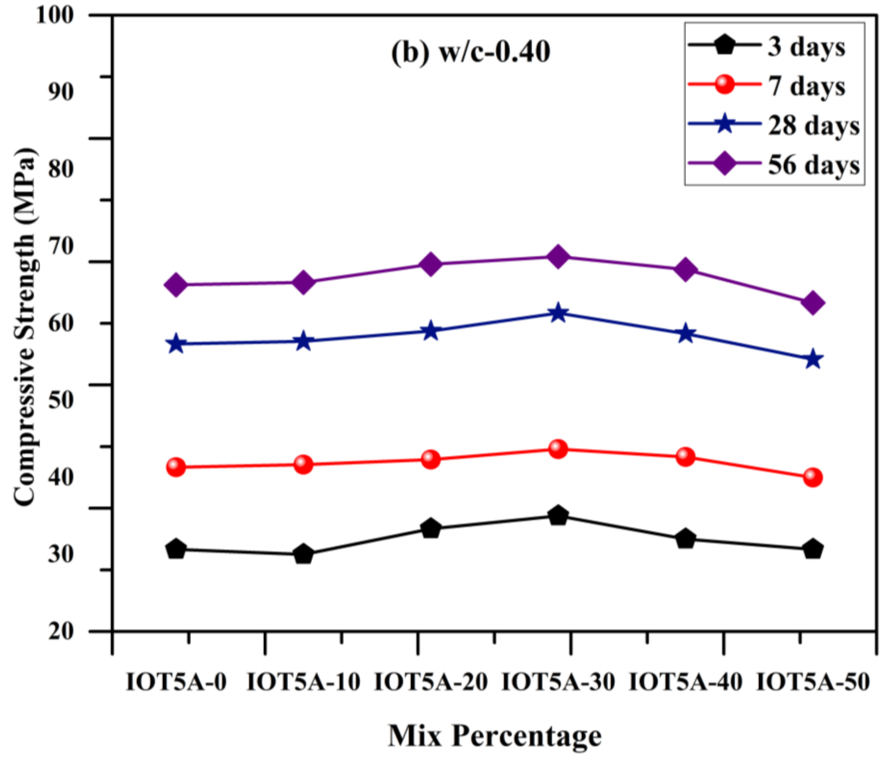
Fig. 4.15 Density for iron ore tailings (IOT) -alccofine in concrete for varying w/c

4.4.3 Influence of IOT-alccofine on compressive strength of concrete

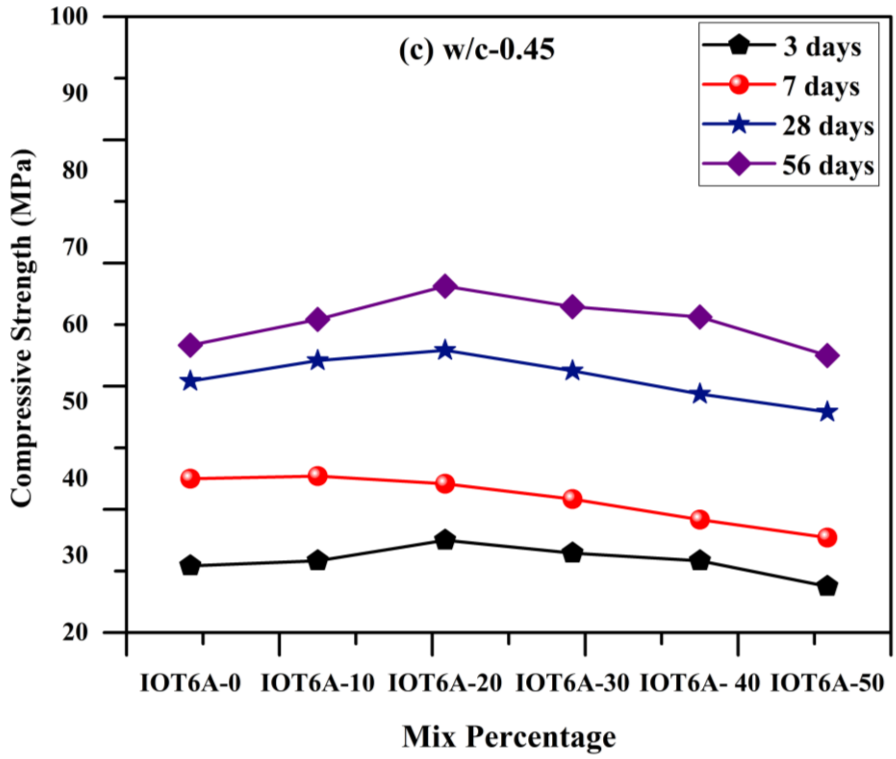
Tests were carried out to analyse the effect of IOT-alccofine concrete on compression of concrete specimens with varying IOT-alccofine mix proportions with reference to the control mix concrete and the results observed are plotted in Fig. 4.16. Wıth reference to control concrete mix, optimum strength obtained at 3 days cured concrete specimens were enhanced by 15.79%, 12.37% and 10.41% for 0.35, 0.40 and 0.45 w/c respectively. Similar strength enhancement trend was observed for 7, 28 and 56 cured concrete specimens for varying w/c as illustrated in Fig. 4.16(a), 4.16(b) and 4.16(c). An increase in strength was observed for each w/c. The maximum compressive strength obtained for w/c 0.35, 0.40 and 0.45 were 63 MPa, 61.33 MPa, 56.67 MPa and 75MPa, 68.67 MPa, 65 MPa at IOT-alccofine replacement of 40%, 30% and 20% respectively for 28 and 56 days cured samples respectively. There was a decrease in trend of compressive strength with the increase in water-cement ratio. The overall strength of concrete was higher with IOT-alccofine replacement than the control mix concrete.



4.16 (a) Compressive strength for w/c-0.35



4.16 (b) Compressive strength for w/c-0.40

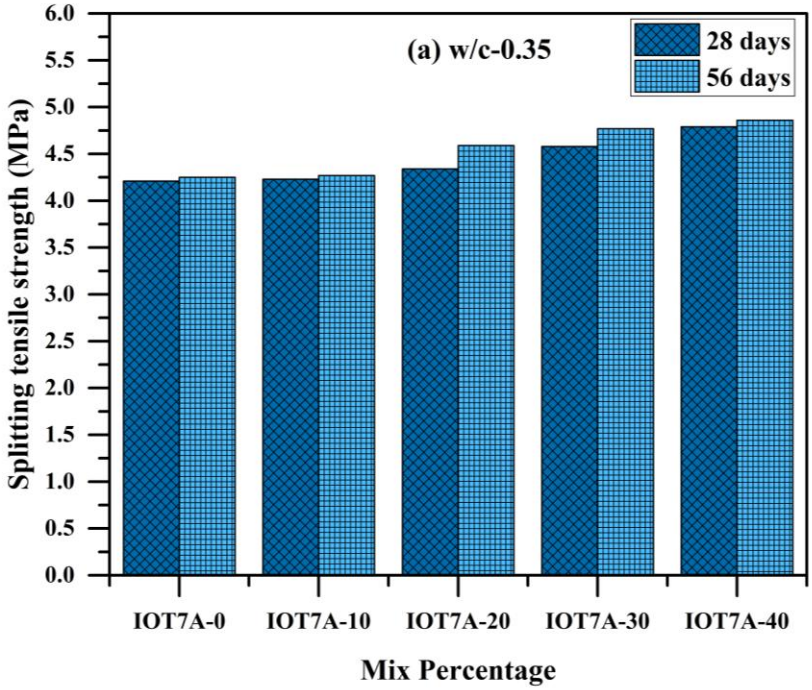


4.16 (c) Compressive strength for w/c-0.45

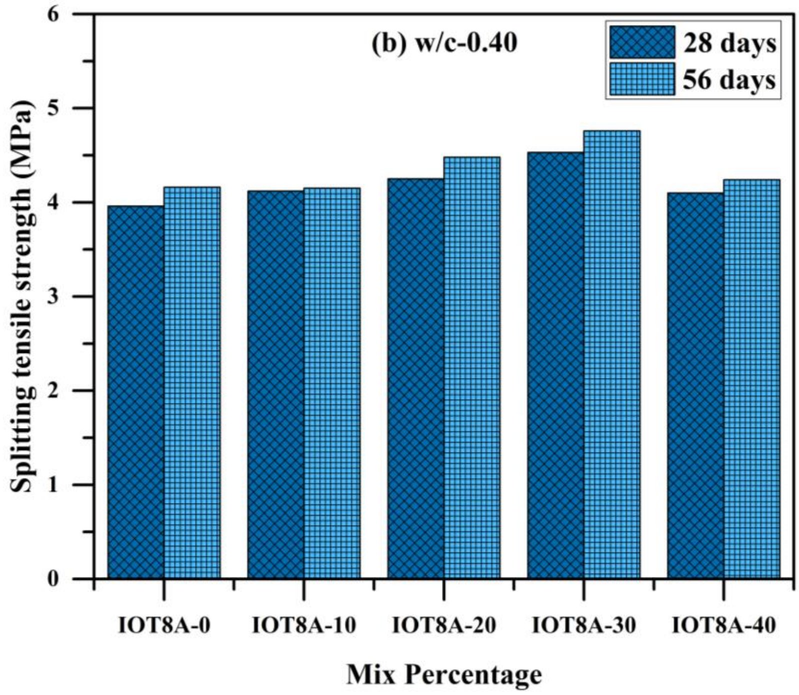
Fig. 4.16 Compressive strength for iron ore tailings (IOT) -alccofine concrete for varying w/c

4.4.4 Influence of IOT-alccofine on splitting tensile strength of concrete

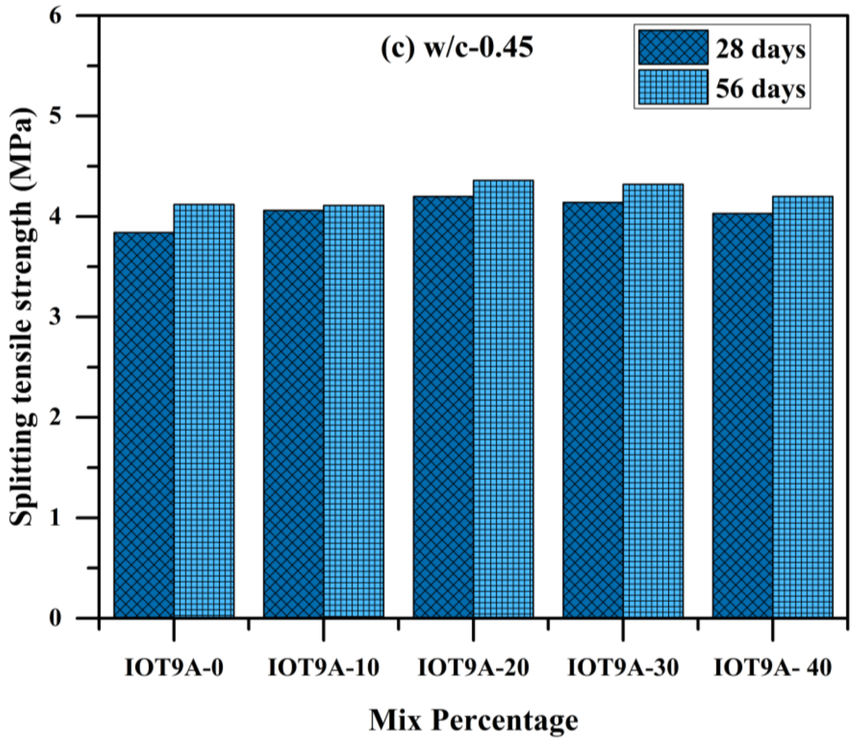
Splitting tensile strength of IOT-alccofine concrete was tested on cylindrical specimens for 28 and 56 curing days at varying w/c of 0.35, 0.40 and 0.45. Strength at 28 and 56 days for 0.35 w/c was enhanced by 12.11% and 12.55% respectively with reference to the control mix concrete at optimum percentage of 40% as illustrated in Fig. 4.17(a). Similarly in the case of 0.40 and 0.45 w/c, strength was enhanced by 12.58%, 12.61% and 8.57%, 5.50% for 28 and 56 days cured specimens at optimum percentage of IOT-alccofine 30% and 20% respectively as illustrated in Fig. 4.17(b) and 4.17(c). An increase in strength was observed for each w/c. The maximum splitting tensile strength obtained for w/c 0.35, 0.40 and 0.45 were 4.86 MPa, 4.76 MPa and 4.36 MPa for IOT-alccofine replacement of 40%, 30% and 20% respectively for 56 days cured samples. With reference to the splitting tensile strength, decrease in trend was observed with increase in w/c.



4.17(a) Splitting tensile strength for w/c-0.35



4.17(b) Splitting tensile strength for w/c-0.40



4.17(c) Splitting tensile strength for w/c-0.45

Fig. 4.17 Splitting tensile strength for iron ore tailings (IOT)-alccofine in concrete for varying w/c

4.4.5 Influence of IOT-alccofine on flexural strength of concrete

Three-point bending tests were carried out to analyse the behavior of IOT-alccofine concrete in flexure. Concrete beams with IOT-alccofine were tested at 28 and 56 days curing for varying w/c of 0.35, 0.40 and 0.45.

Flexural strength of IOT-alccofine concrete tested on concrete beams at 28 and 56 days curing resulted in enhanced strength with reference to the control mix concrete for 0.35, 0.4 and 0.45 w/c by 7.84%, 11.11% ; 11.34%, 9.90% and 4.55%, 5.38% respectively with their optimum percentage of 40%, 30% and 20% IOT-alccofine replacement for each w/c as illustrated in Fig. 4.18(a), Fig. 4.18(b) and Fig. 4.18(c).
In comparison within w/c, flexural strength decreased with increase in w/c of 0.35, 0.40 and 0.45.

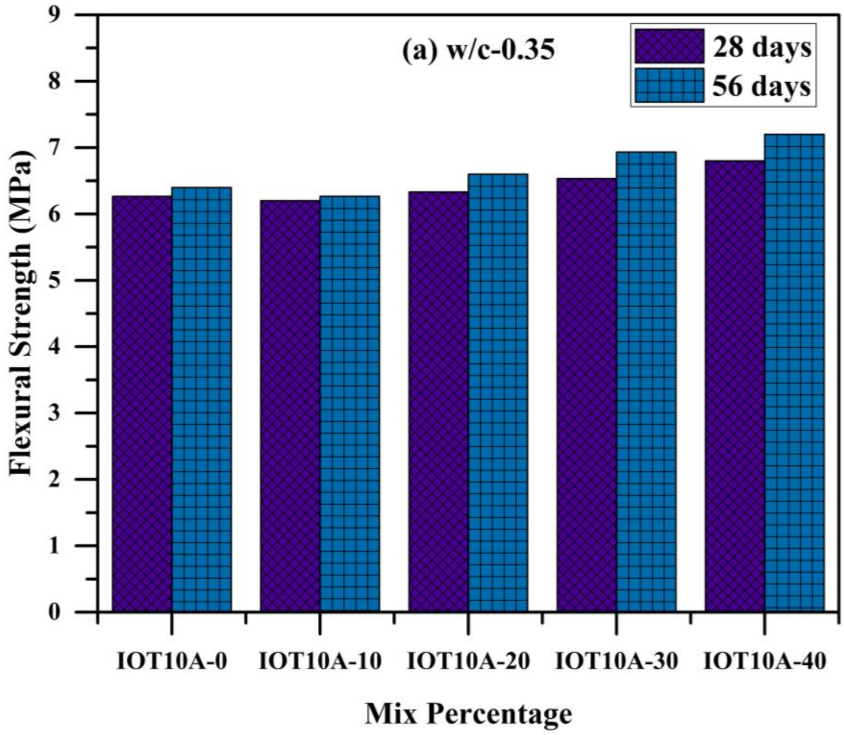


Fig. 4.18(a) Flexural strength for w/c-0.35

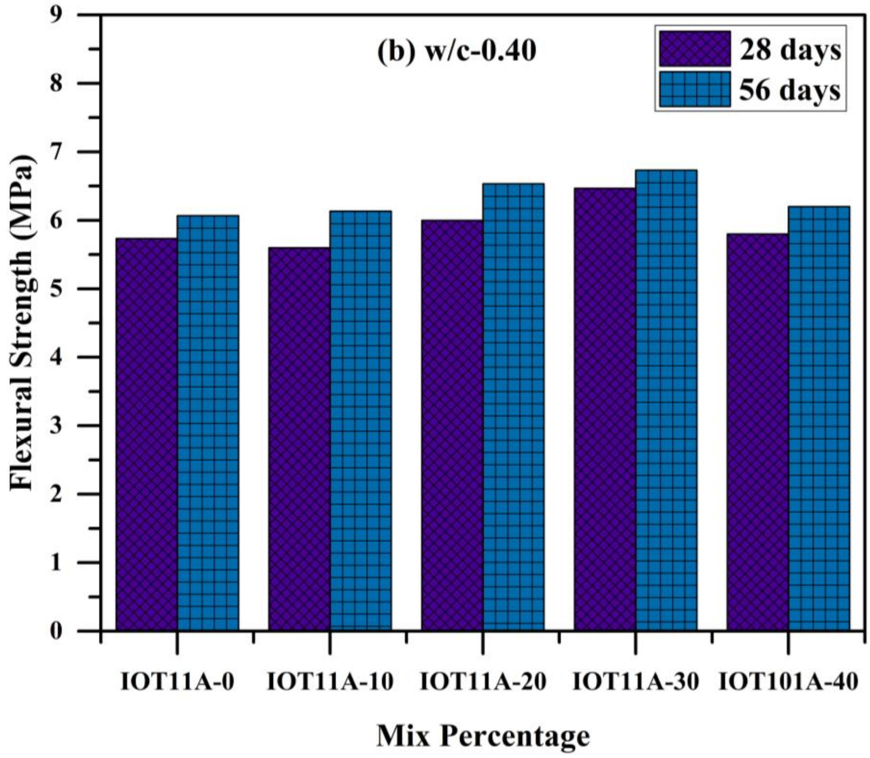


Fig. 4.18(b) Flexural strength for w/c-0.40

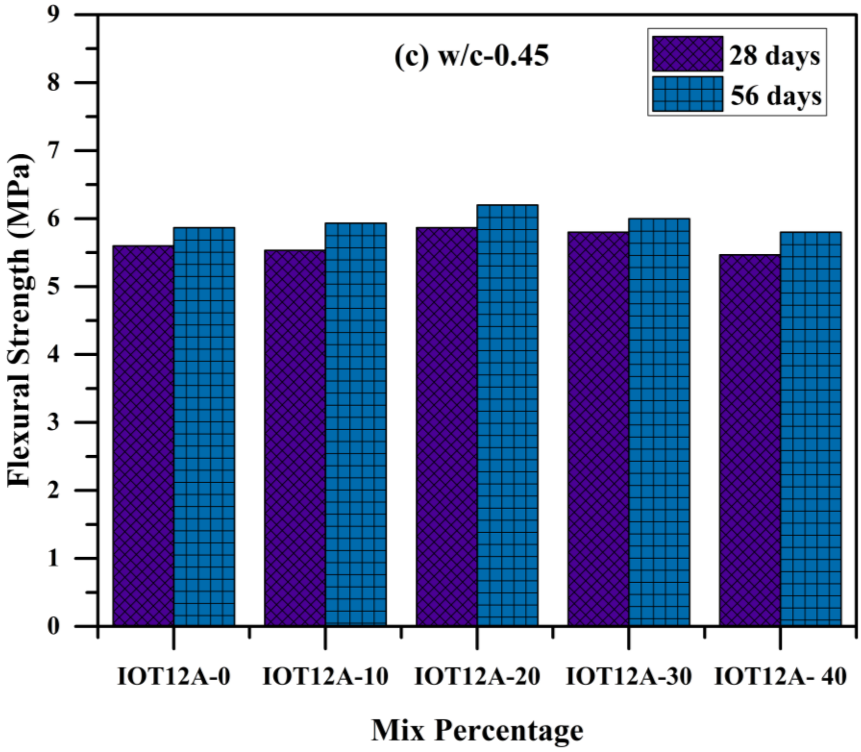


Fig. 4.18(c) Flexural strength for w/c-0.45

Fig. 4.18 Flexural strength for IOT-alccofine in concrete for varying w/c

4.5 Production of Concrete with Optimum WR-IOT-Alccofine and Expanded Perlite (EP)

Based on the laboratory investigations for WR-alccofine concrete and IOT-alccofine concrete, optimum percetages of each mix was considered for each w/c respectively in this sesction. In the case of WR-alccofine concrete, optimum strength obtained at 0.35, 0.40 and 0.45 w/c were at 50%, 40% and 30% respectively. Sımilarly in the case of IOT-alccofine concrete, optimum was obtained at 40%, 30%, 20% at 0.35, 0.40 and 0.45 w/c respectively. Due to the high density of the iron ore waste rock and tailings, the concrete density also increases. To reduce the density, expanded perlite (EP) was considered as a density controller as partial replacement for fine aggregates in very small percentages by volume. EP was varied by 0%, 2.5%, 5.0%, 7.5% and 10.% for mix consisting of optimum percentages of WR-alccofine and IOT-alccofine concrete.

4.5.1 Influence of expanded perlite (EP) with optimum WR-IOT-alccofine on workability of concrete

Concrete was designed for M40 grade concrete. Influence of WR-IOT-alccofine and EP on workability of concrete was measured using slump cone. Slump values for different concrete mixes for varying w/c is illustrated in Fig. 4.19. As discussed, optimum percentage obtained from the experimental investigations of WR-IOT-alccofine concrete is considered as control mix and EP is varied at 0%, 2.5%, 5.0%, 7.5% and 10% as fine aggregates for varying w/c 0.35, 0.40 and 0.45. Based on the observations, workability decreased with increase in EP content with reference to the control mix. Whereas, increase in workability was observed for varying w/c. The slump values ranged between 35-40 mm depicting that the designed concrete is workable. Slump values are higher for WR-IOT-alccofine as aggregates in control mix concrete whereas, with addition of EP, workability decreased due to the water absorption of EP in concrete.

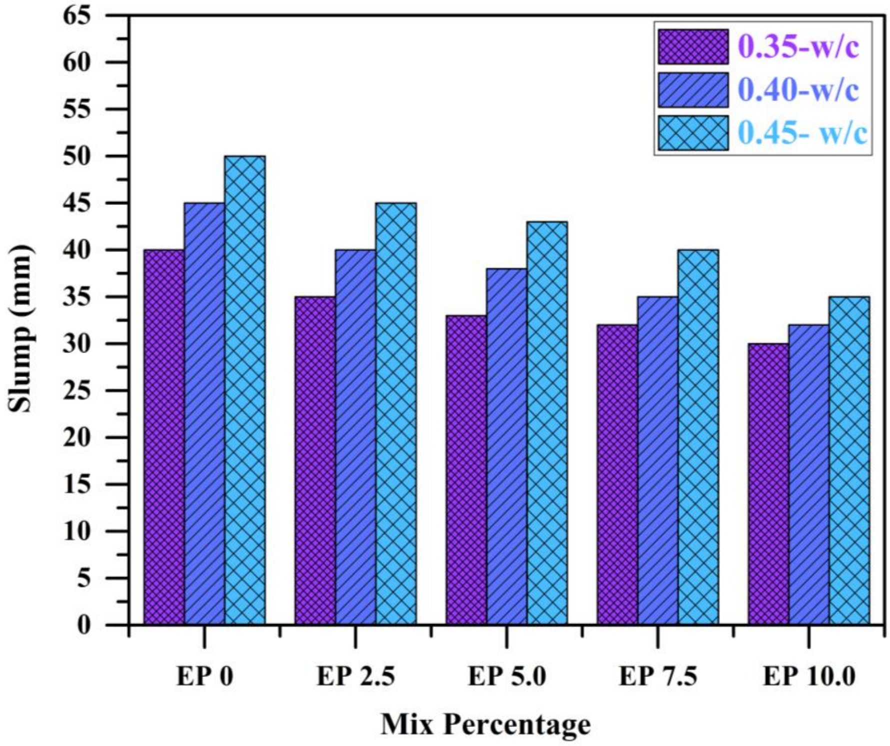


Fig. 4.19 Workability for expanded perlite (EP) concrete for varying w/c

4.5.2 Influence of expanded perlite (EP) with optimum WR-IOT-alccofine on density of concrete

The density of EP concrete with different mix proportions at varying w/c and curing days were determined. The density gradually decreased with mix proportion consisting of optimum percentage of WR-IOT-alccofine at 50-40-10, 40-30-10 and 30-20-10% for 0.35, 0.40 and 0.45 w/c respectively and EP varied in the range of 0%, 2.5%, 5.0%, 7.5% and 10%. Decreasing trend in density was observed for increasing quantity of EP in concrete.

From Fig. 4.20 (a), it can be observed that 3 days cured specimens shows decrease in density by 5%, 6%, 7%, 9% and 0% with increasing percentage of EP from 0%-10% with 2.5% interval. Similar trend was observed for 7, 28 and 56 days cured specimens. Density decreased from 2637 kg/m^3 to 2380 kg/m^3 for 28 days cured specimens and 2646 kg/m^3 to 2383 kg/m^3. Maximum decrease in density was observed for concrete mixes with 10% EP replacement. Decreasing trend was observed with respect to the curing days for 0.40 w/c i.e., from 2631 kg/m^3 to 2377 kg/m^3 for 28 days cured specimens and 2632 kg/m^3 to 2380 kg/m^3 for 56 days cured specimens as illustrated in Fig. 4.20 (b). Similar decreasing trend in density was observed with reference to curing days for 0.45 w/c for 28 days and 56 days cured specimen i.e., from 2620 kg/m^3 to 2374 kg/m^3 and 2626 kg/m^3 to 2375 kg/m^3 respectively as illustrated in Fig. 4.20(c). The results depict that, high dense concrete is reduced to a low dense concrete with addition of EP.

4.5.3 Influence of expanded perlite (EP) with optimum WR-IOT-alccofine on compressive strength of concrete

Compressive strength for concrete specimens with varying percentages of EP with optimum percentages of WR-IOT-alccofine was tested.

Concrete specimens show reduction in compressive strength with addition of expanded perlite (EP). Maximum strength was observed in control mix concrete consisting of optimum percentages of WR-IOT-alccofine content for respective w/c. For 3, 7, 28 and 56 days cured concrete specimens at 0.35 w/c, strength declined with reference to control mix by 9%, 7%, 10%, 24% ; 17%, 14%, 16%, 21% ; 11%, 8%, 12%, 13% ; 9%, 5%, 7%, 11% respectively for varying percentage of EP from 2.5%-10% with 2.5% interval respectively as illustrated in Fig. 4.21(a). Similar trend was observed in case of 0.40 and 0.45 w/c at varying curing days of 3, 7, 28 and 56 days as illustrated in Fig. 4.21(b) and 4.21(c).

Maximum strength was observed at control mix consisting of optimum percentage of WR-IOT-alccofine around 58 MPa for all the w/c considered. In all the three w/c variation, compressive strength was maximum with 5% EP content in concrete.

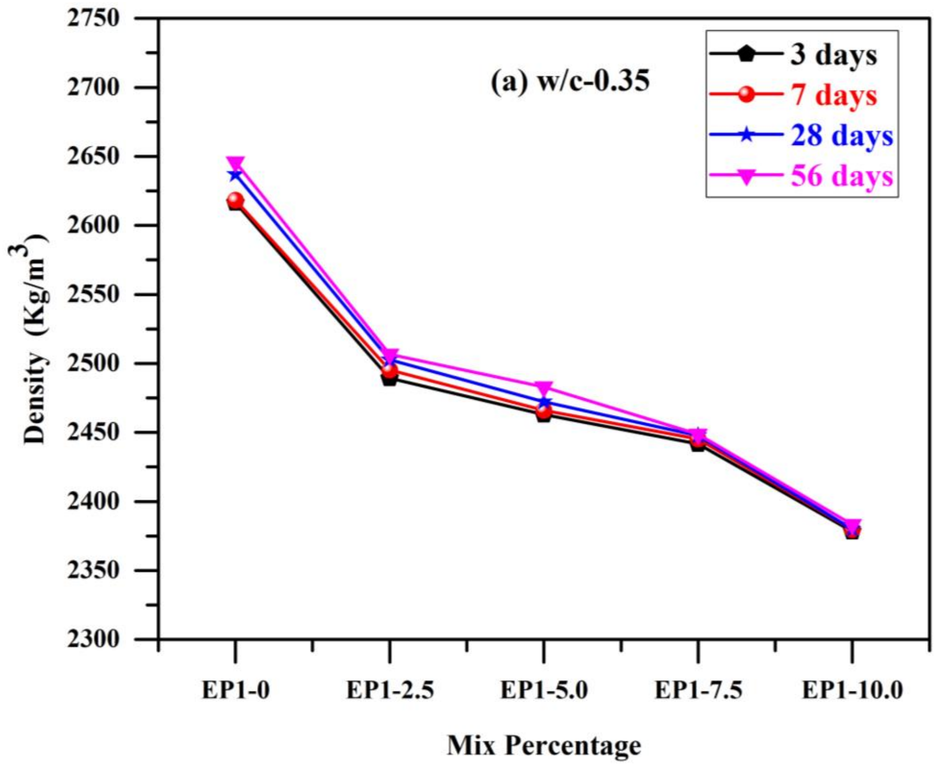


Fig. 4.20 (a) Density for w/c-0.35

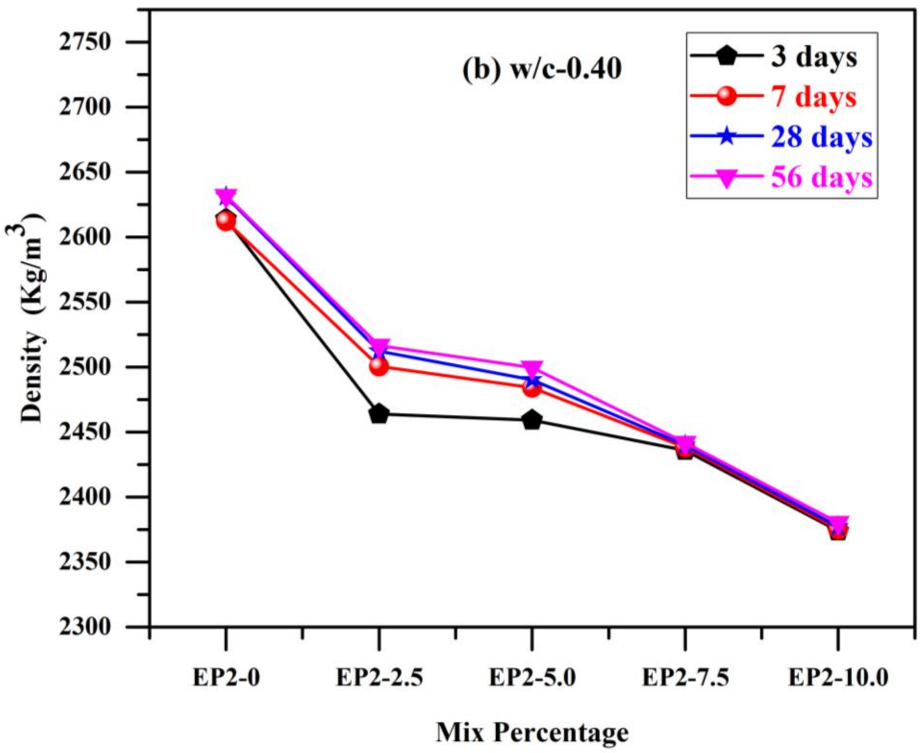


Fig. 4.20 (b) Density for w/c-0.40

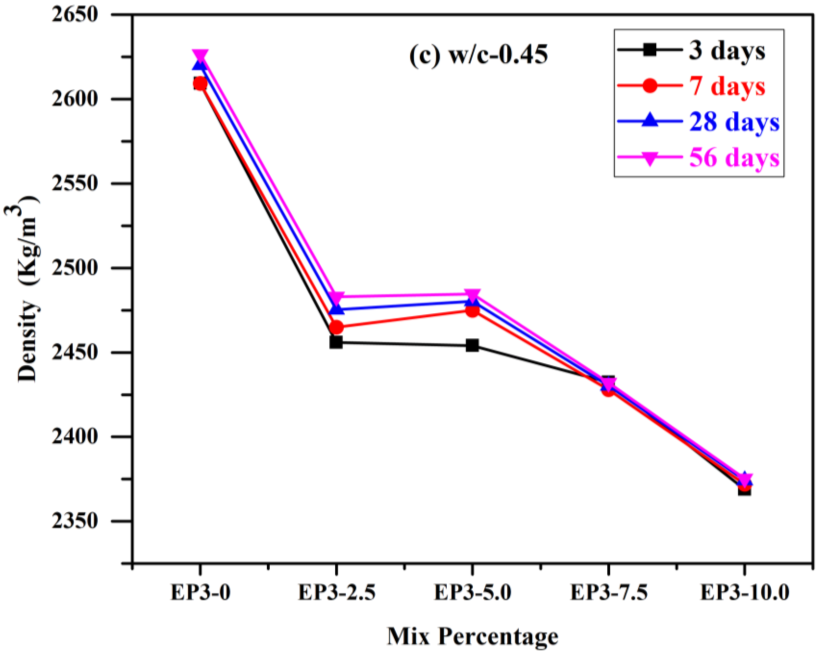


Fig. 4.20 (c) Density for w/c-0.45

Fig. 4.20 Density for expanded perlite (EP) concrete for varying w/c

4.5.4 Influence of expanded perlite (EP) with optimum WR-IOT-alccofine on compressive strength of concrete

Compressive strength for concrete specimens with varying percentages of EP with optimum percentages of WR-IOT-alccofine was tested. Concrete specimens show reduction in compressive strength with addition of expanded perlite (EP). Maximum strength was observed in control mix concrete consisting of optimum percentages of WR-IOT-alccofine content for respective w/c. Concrete specimens for 0.35 w/c, strength declined with reference to control mix by 9%, 7%, 10%, 24% ; 17%, 14%, 16%, 21% ; 11%, 8%, 12%, 13% ; 9%, 5%, 7%, 11% respectively for varying percentage of EP from 2.5%-10% with 2.5% interval respectively for 3, 7, 28 and 56 days curing as illustrated in Fig. 4.21(a). Similar trend was observed in case of 0.40 and 0.45 w/c at varying curing days of 3, 7, 28 and 56 days as illustrated in Fig. 4.21(b) and 4.21(c).

Maximum strength was observed at control mix consisting of optimum percentage of WR-IOT-alccofine around 58 MPa for all the w/c considered. In all the three w/c variation, compressive strength was maximum with 5% EP content in concrete.

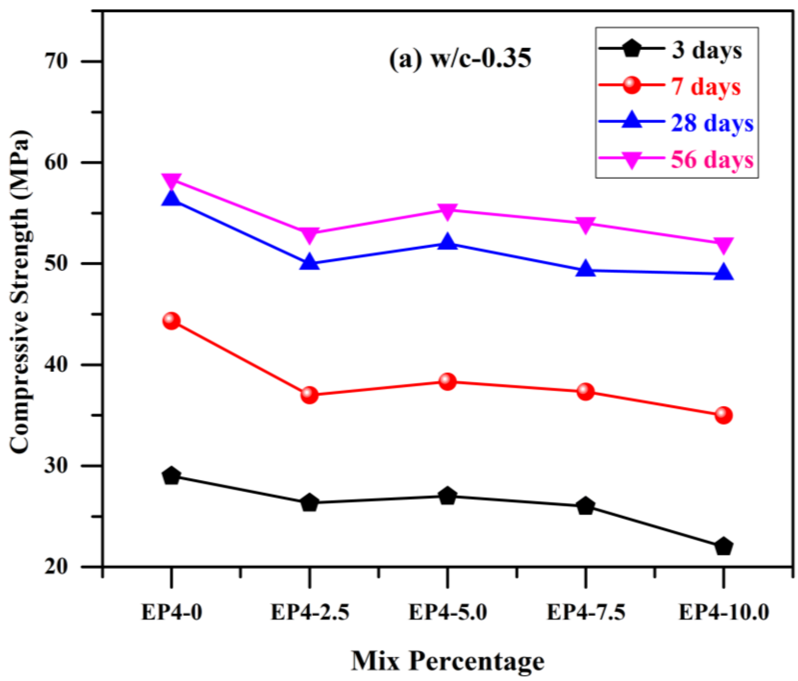


Fig. 4.21(a) Compressive strength for w/c-0.35

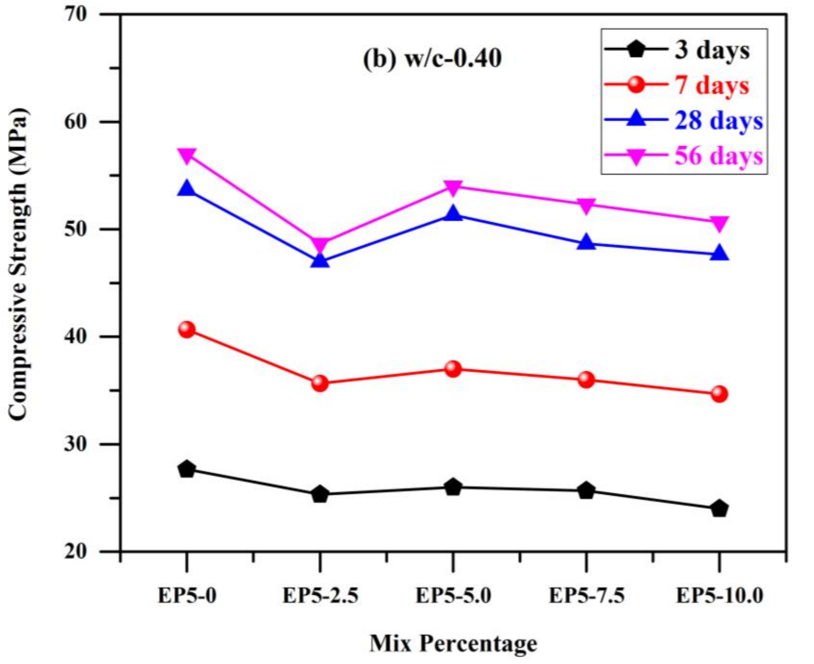


Fig. 4.21(b) Compressive strength for wc-0.40

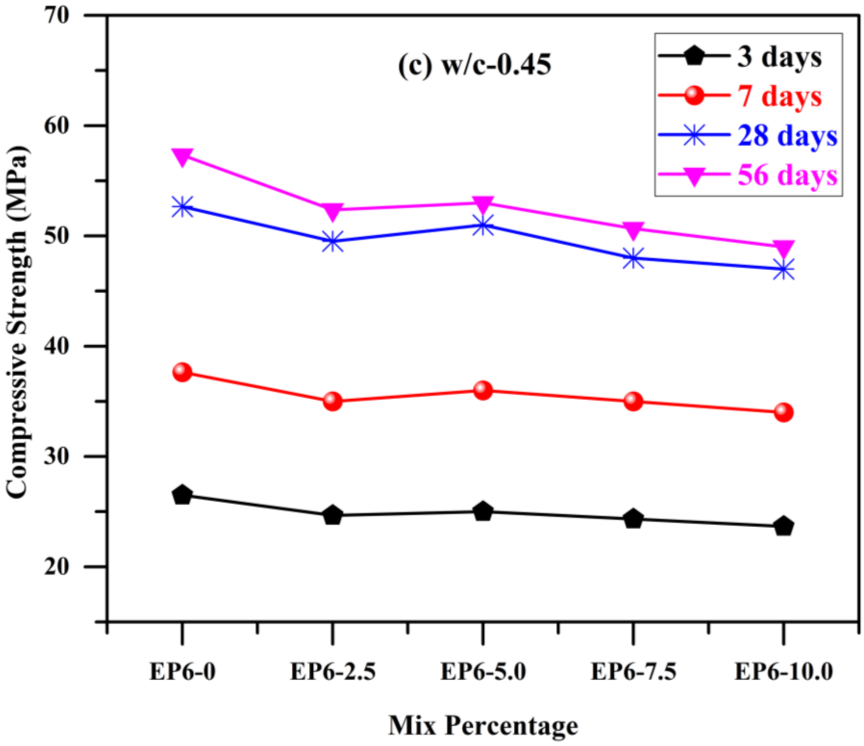


Fig. Compressive strength for 4.21(c)

Fig. 4.21 Compressive strength for expanded perlite (EP) concrete for varying w/c

4.5.5 Influence of expanded perlite (EP) on splitting tensile strength of concrete

The splitting tensile strength was carried out on concrete cylinders as per IS standards on 28 and 56 days cured concrete specimens at varying w/c of 0.35, 0.40 and 0.45.

EP concrete specimens tested at 28 and 56 cured days depicted reduction in strength by 8.43%, 4.82%, 7.23%, 9.64% and 5.88%, 4.71%, 8.24%, 10.59% repectively with reference to the concrol mix concrete consisting of WR-IOT-alcoffine at 0.35 w/c as illustrated in Fıg. 4.22(a). In the case of 0.40 w/c, EP concrete specimens depited decrease in strength further in comparison to 0.35 w/c. Stregth reduced by 9.88%, 6.17%, 8.64%, 12.35%; 4.82%, 1.20%, 3.61%, 7.23% with reference to control mix concrete at 0.40 for 28 and 56 days cured specimens (Fig. 4.22(b)). Similar reducing trend in strength was observed for concrete specimens cured at 28 and 56 days by 11.54%, 3.85%, 5.13%, 11.54% and 7.32%, 3.66%, 2.44%, 7.32% respectively at 0.45 w/c as shown in Fıg. 4.22(c).

In comparison within w/c, at 0.35 w/c, the control mix shows the highest strength whereas optimum strength of 3.77 and 3.82 MPa was observed for 5.0% EP replacement i.e., a decrease by 4.70% was observed with reference to the control mix at 28 and 56 curing days respectively. At 0.40 w/c, the maximum strength of 3.59 and 3.87 MPa was observed for 5.0% EP replacement and similarly for 0.45 w/c, the optimum mix was observed at 5.0% IOT replacement with 3.54 and 3.73 MPa.

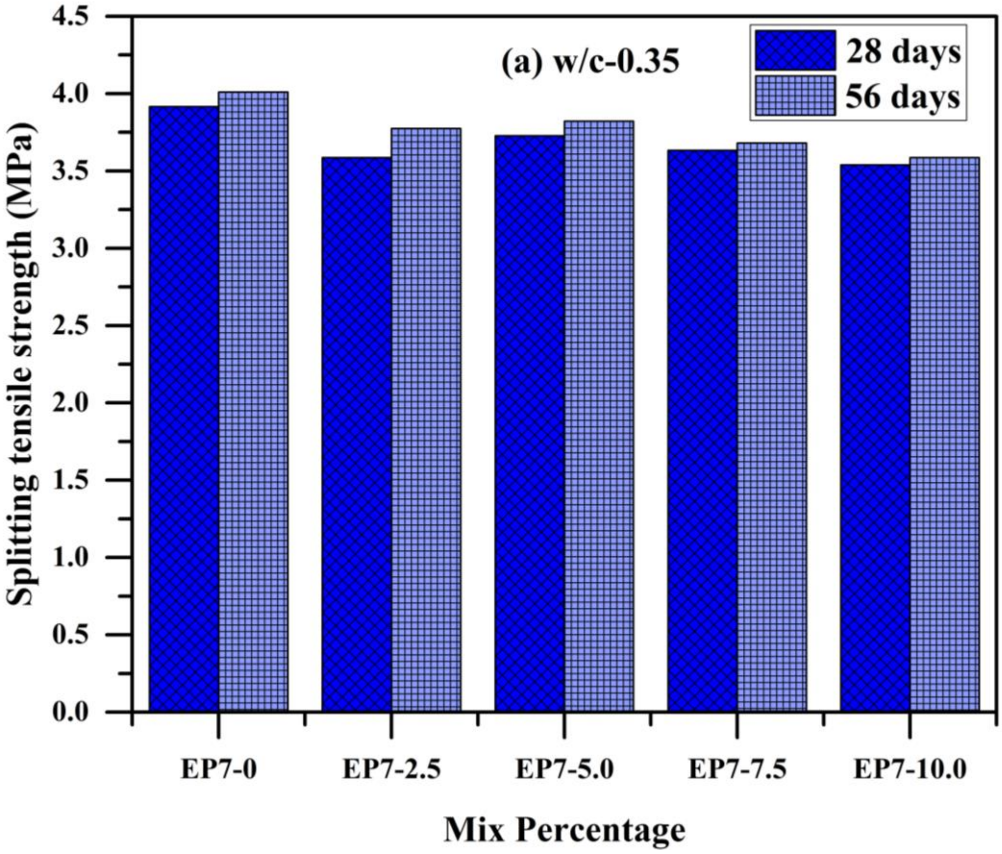


Fig. 4.22(a) Splitting tensile strength for w/c-0.35

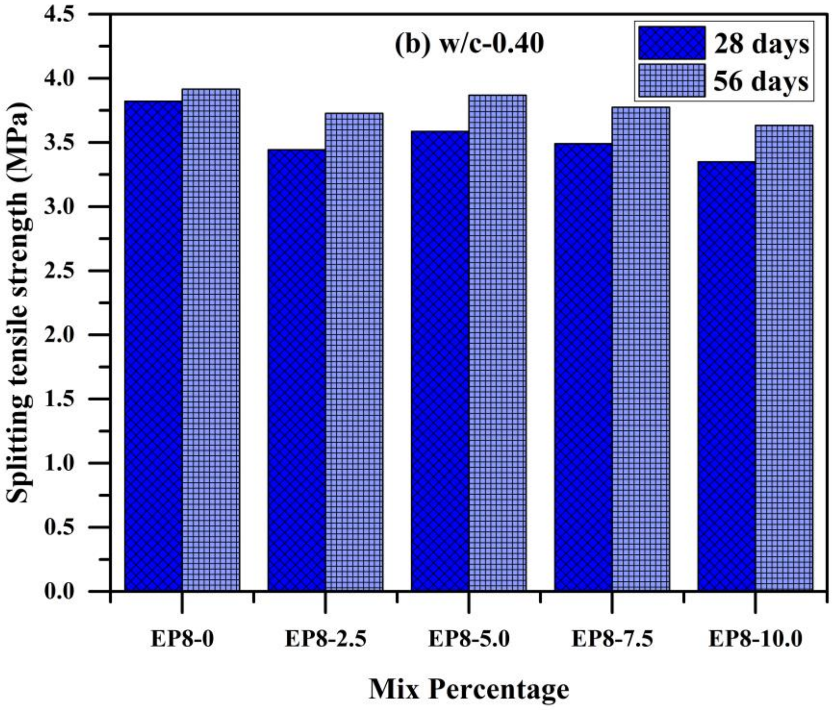


Fig. 4.22(b) Splitting tensile strength for w/c-0.40

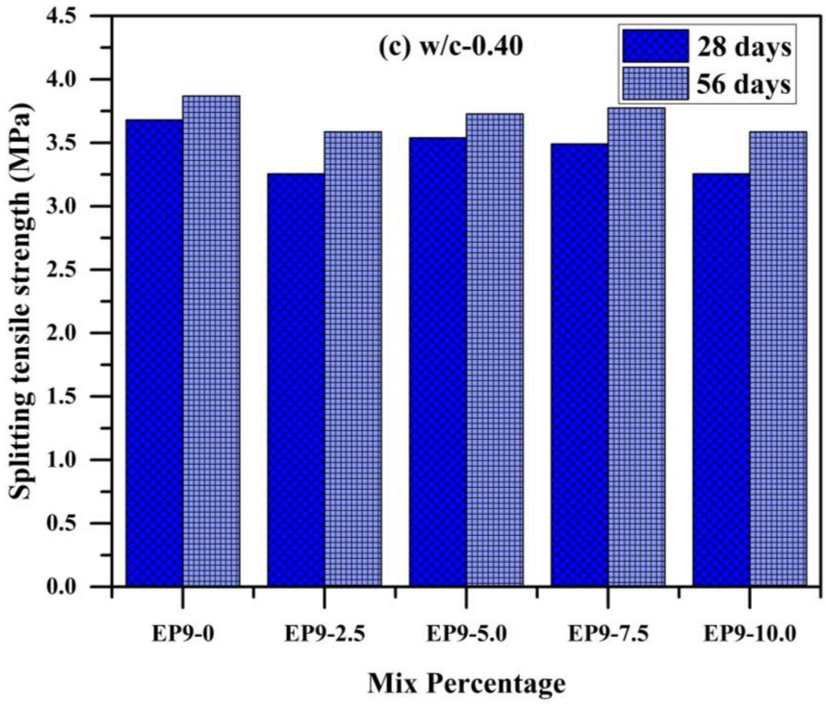


Fig. 4.22(c) Splitting tensile strength for w/c-0.45

Fig. 4.22 Splitting tensile strength for expanded perlite (EP) concrete for varying w/c

4.5.6 Influence of expanded perlite (EP) on flexural strength of concrete

The flexural strength of the concrete mixes with varying percentage of EP was determined using three point bending load as per IS standards. The flexural strength of EP concrete was tested on beams of 100x100x500 mm dimension for 28 and 56 days cured specimens. Flexural strength for 28 and 56 days cured EP concrete specimens were tested and resulted in reduction of strength with reference to control mix concrete by 6.13%, 5.32%, 10.81%, 12.10% and 8.13%, 7.50%, 15.31%, 16.41% respectively at 0.35 w/c as illustrated in Fig. 4.23(a). Similarly in case of 0.40 and 0.45 w/c for specimens cured at 28 and 56 days, similar reduction in strength was observed with reference to control mix as illustrated in Fig. 4.23(b) and 4.23(c). Optimum strength obtained with replacement of EP from 2.5 to 10% with 2.5% interval is at 5.0% replacement EP content along with WR-IOT-alccofine content. The flexural strength at 0.35 w/c for 28 and 56 days cured specimens obtained is 5.87 MPa and 5.92 MPa respectively. At 0.40 w/c, strength observed is 5.67 MPa and 5.74

MPa and at 0.45 w/c, strength observed is 5.54 MPa, 5.67 MPa for 28 and 56 days respectively. Strength declined with increased w/c in EP concrete specimens.

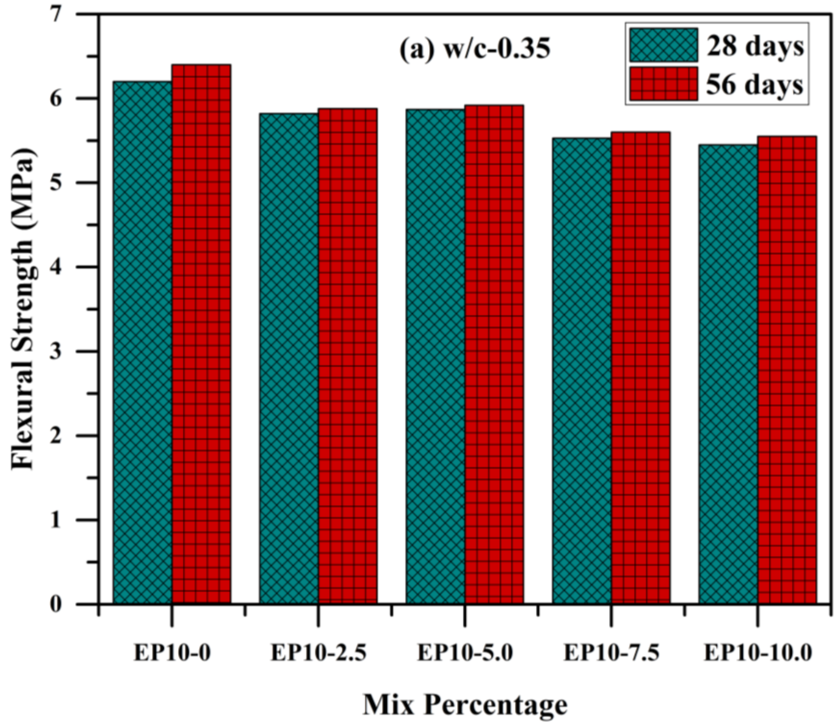


Fig. 4.23(a) Flexural strength for 0.35 w/c

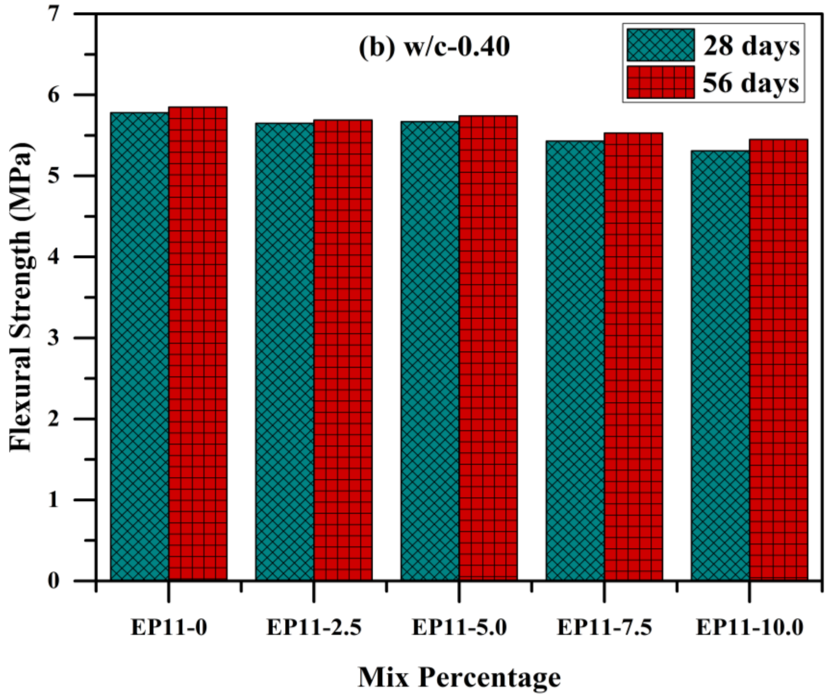


Fig. 4.23(b) Flexural strength for 0.40 w/c

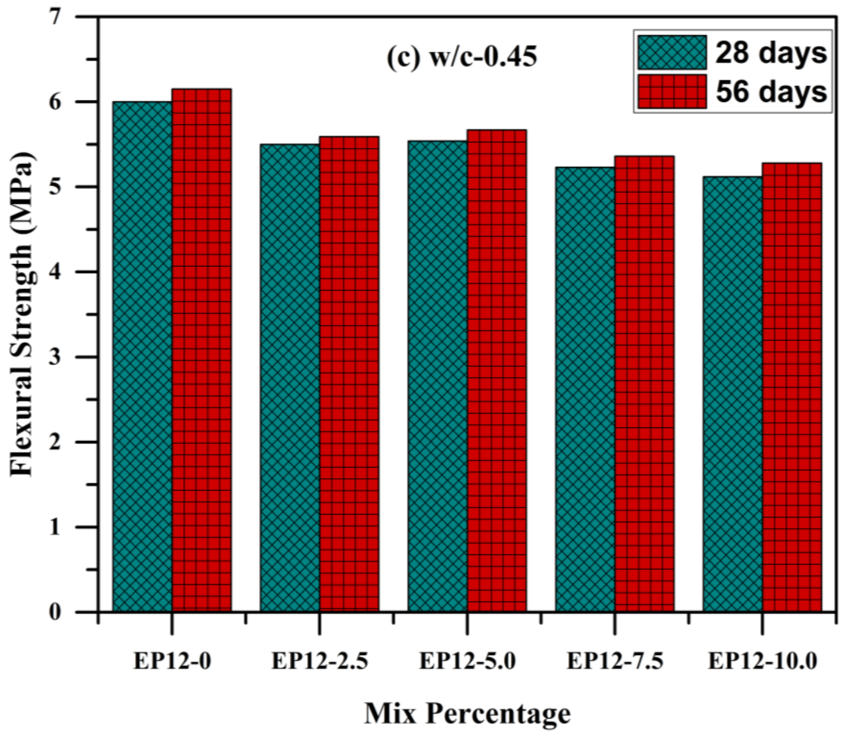


Fig. 4.23(c) Flexural strength for 0.40 w/c

Fig. 4.23 Flexural strength for expanded perlite (EP) concrete for varying w/c

4.6 Durability Properties of Concrete

This section deals with the durability property by rapid chloride permeability test (RCPT) of concrete mixes.

4.6.1 Rapid chloride permeability test (RCPT)

Rapid chloride permeability test (RCPT) was conducted as per AASHTO T 277 or ASTM C1202 on (i) WR-alccofine concrete (ii) IOT-alccofine concrete and (iii) EP concrete mixes for 28 and 56 days cured specimens.

Charge passed for WR-alccofine, IOT-alccofine and EP concrete mixes shows lower values in comparison to their respective control mix concrete as illustrated in Fig. 4.24, Fig. 4.25 and Fig. 4.26 respectively. Permeability of concrete reduced with the increase of marginal aggregates used in this research study.

Iron ore waste rock (WR) as coarse aggregates, iron ore tailings (IOT) as fine aggregates, expanded perlite (EP) as admixture and alccofine as replacement for binder material reduced the pores of concrete specimens making the concrete impermeable. Permeability of concrete is influenced on the internal pore structure which depends on the hydration of cement paste. (Ann et al. 2008) investigated the influence of fly ash and blast furnace slag on the concrete's resistance to chloride ion penetration and the results indicated the development in the concrete resistance to chloride ion penetration with the addition of fly ash and blast furnace slag (Saleh Ahari et al. 2015). More the free chloride ion in the concrete, lesser the compressive strength and accelerated the process of corrosion of steel reinforcement in concrete (Lima et al. 2013)

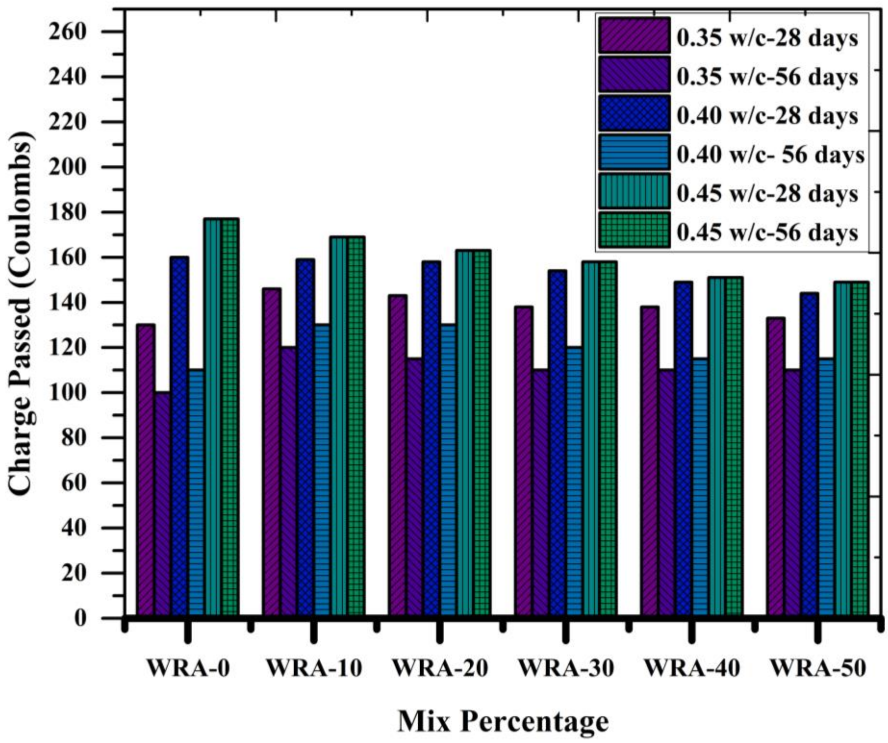


Fig. 4.24 Rapid chloride permeability test (RCPT) for waste rock (WR)-alccofine concrete

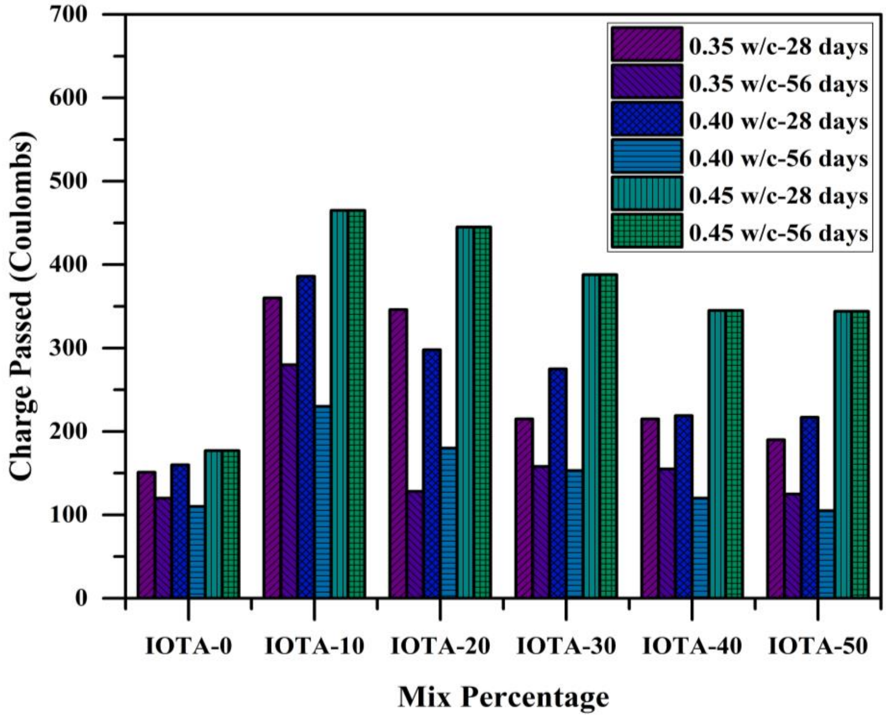


Fig. 4.25 Rapid chloride permeability test (RCPT) for iron ore tailings (IOT)-alccofine concrete

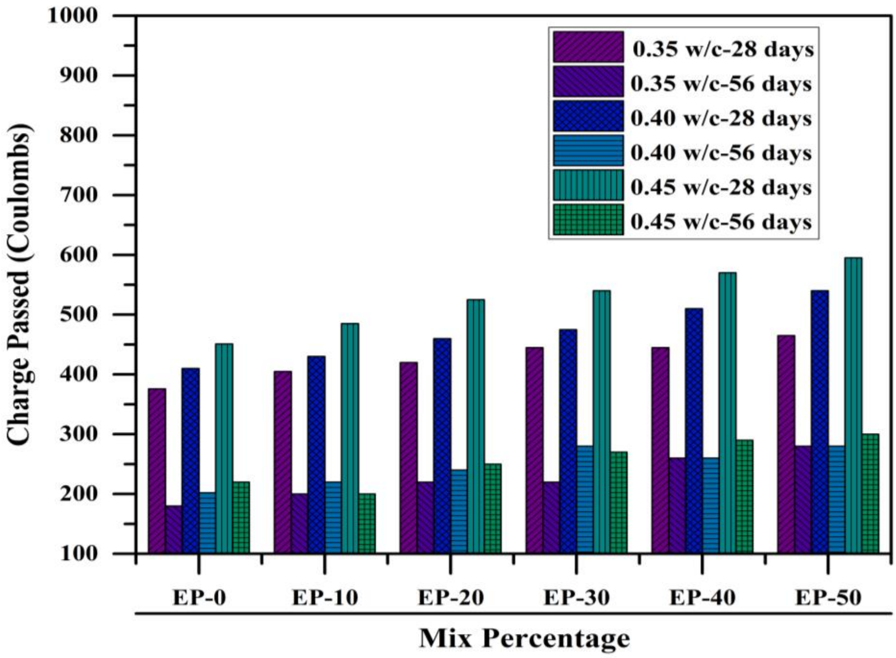


Fig. 4.26 Rapid chloride permeability test for expanded perlite (EP) concrete

4.7 Cost Analysis

The cost of concrete is an important factor due to its enormous usage in the construction industry. The quantity of materials in dry state required for the production of $1m^3$ of concrete. The labour required for producing concrete would remain same for different concrete mix presented below and hence the labour aspect is not considered in rate analysis. Also transportation charges are not considered in the analysis.

Cost analysis was done for the optimum concrete mixes with WR-alccofine, IOT-alccofine and EP concrete as shown in Table 4.1 to 4.5. Optimum percentage for WR-alccofine concrete was considered as 40% i.e., for 0.40 w/c. In case of IOT-alccofine concrete, optimum percentage was considered as 30% i.e., for 0.40 w/c and for EP concrete also; the optimum percentage was considered as 5% i.e., for 0.40 w/c.

A reduction in cost is observed by 2%, 5%, 8% and 9% with replacement of IOT-alccofine, WR-alccofine, optimum percentage of IOT and WR-alccofine and EP-alccofine concrete respectively.

Table 4.1 Cost analysis for control mix concrete

Concrete mix	**Material**		**Quantity**	**Price (Rs.)**		**Cost (Rs.)**	**Cost per $1m^3$ of concrete (Rs.)**
Control Mix	Cement		7.72	bags	370	per bag (50 kg)	2856.4
	Alccofine		1.72	kg	43	per kg	73.96
	Coarse Aggregate		0.41	m^3	1175	per m^3	481.75
	Fine Aggregate	Sand	0.3	m^3	1200	per m^3	360
		IOT	0	m^3	0	per m^3	0
							3,772.11

Notation: WR-Waste Rock

IOT- Iron Ore Tailings

EP- Expanded Perlite

Table 4.2 Cost analysis for WR –alccofine concrete with 40% optimum WR

Concrete mix	**Material**		**Quantity**	**Price (Rs.)**		**Cost (Rs.)**	**Cost per 1m^3 of concrete (Rs.)**
WR-Alccofine Concrete	Cement		7.8	bags	370	per bag (50 kg)	2886
	Alccofine		0	kg	43	per kg	0
	Coarse Aggregate	Crushed granite	0.246	m^2	1175	per m^2	289.05
		WR	0.164	m^3	0	per m^3	0
	Fine Aggregate	Sand	0.3	m^3	1200	per m^3	360
			0	m^3		per m^3	0
							3,535.05

Table 4.3 Cost analysis for IOT –alccofine concrete with 30% optimum iron ore tailings (IOT)

Concrete mix	**Material**		**Quantity**	**Price (Rs.)**		**Cost (Rs.)**	**Cost per 1m^3 of concrete (Rs.)**
IOT Concrete	Cement		7.72	bags	370	per bag (50 kg)	2856.4
	Alccofine		1.72	kg	43	per kg	73.96
	Coarse Aggregate		0.41	m^3	1175	per m^3	481.75
	Fine Aggregate	Sand	0.21	m^3	1200	per m^3	252
		IOT	0.09	m^3	0.07	per m^3	0.0063
							3,664.12

Table 4.4 Cost analysis for iron ore tailings (IOT)-waste rock (WR) –alccofine

Concrete mix	Material		Quantity	Price (Rs.)		Cost (Rs.)	Cost per $1m^3$ of concrete (Rs.)
IOT-WR-Alccofine concrete	Cement		7.8	bags	370	per bag (50 kg)	2886
	Alccofine		0	kg	43	per kg	0
	Coarse Aggregate	Crushed granite	0.246	m^2	1175	per m^2	289.05
		WR	0.164	m^3	0	per m^3	0
	Fine Aggregate	Sand	0.21	m^3	1200	per m^3	252
		IOT	0.09	m^3	0.07	per m^3	0.0063
							3,427.06

Table 4.5 Cost analysis for waste rock (WR) –alccofine concrete with 5% expanded perlite (EP)

Concrete mix	Material		Quantity	Price (Rs.)		Cost (Rs.)	Cost per $1m^3$ of concrete (Rs.)
Control Mix	Cement		7.8	bags	370	per bag (50 kg)	2886
	Alccofine		0	kg	43	per kg	0
	Coarse Aggregate	Crushed granite	0.246	m^2	1175	per m^2	289.05
		WR	0.164	m^3	0	per m^3	0
	Fine Aggregate	Sand	0.1995	m^3	1200	per m^3	239.4
		IOT	0.09	m^3	0.07	per m^3	0.0063
		Expanded Perlite (EP)	0.0105	m^4	35	per kg	0.3675
							3414.46

4.8 Statistical Analysis

Multiple regression models were developed using 50 data set and 22 data set were used to validate each parameteric study. The models were developed using MINITAB-17.

The models are developed to predict density, compressive strength, splitting tensile strength and flexural strength using the input parameters viz., water-cement ratio (w/c), mix percentage (Mp), curing days (Cd) for WR-alccofine, IOT-alccofine and EP concrete mixes.

4.8.1. Prediction models for waste rock (WR)-alccofine concrete

Regression models were developed to predict the density, compressive strength, splitting tensile strength and flexural strength of WR-alccofine concrete as shown in Table 4.2, considering the water-cement ratio (w/c), mix percentage (Mp), curing days (Cd) as input variables for WR-alccofine concrete. In the present study, regression models were developed using backward elimination method to eliminate the independent variables which do not influence the dependent variable. Based on the ANOVA analysis, to find the percentage contribution on input parameters (water-cement ratio (w/c), percentage (%) replacement, curing days (Cd)) on output parameters (density, compressive strength, splitting tensile strength, flexural strength), the F (estimated) value of input parameters is greater than F tabulated value also when the P value of input parameters is less 0.05, then the input parameters are statistically significant within the expected range. The observed versus predicted values of density, compressive strength, splitting tensile strength and flexural strength plots are illustrated in Fig. 4.25, Fig. 4.26, Fig. 4.27 and Fig. 4.28 respectively. İt is observed that only one outlier point is seen in the scatter plots. The regression co-efficients are obtained using 70% of the data to develop the model. The majority of observed values were within the predicted ranges. Hence, from this data it is apparent that the model predicts the parameters accurately.

To validate the model, remaining 30% of the data is considered and experimentally measured values and predicted values are compared. The percentages of errors are within the range of 10% and hence the model developed can certainly help in the mix design optimization.

The analysis of variance (ANOVA) test summary and parametric estimates are given in Table 4.3 and 4.4 respectively. Table 4.3 indicates that the model is robust as the P values are less than 0.05 and R^2 is greater than 85% and Table 4.4 shows that all the independent variables were significant at 95% confidence level.

Prediction models for density, compressive strength, splitting tensile strength and flexural strength for WR-alccofine concrete are given below:

Density (Kg/m^3) = 2567.2 - 184.3 w/c + 3.281 Cd + 9.41 Mp - 0.0318 Cd*Cd - 0.0527 Mp*Mp - 11.07 w/c*Mp **Eq. (4.1)**

Compressive strength (MPa) = 51.63 - 48.18 w/c + 1.1215 Cd + 0.3867 Mp - 0.00972 Cd*Cd - 0.00576 Cd*Mp **Eq. (4.2)**

Splitting tensile strength (MPa) = 4.393 - 1.581 w/c + 0.00845 Cd + 0.01502 Mp

Eq. (4.3)

Flexural strength (MPa) = 23.00 - 81.7 w/c + 0.00964 Cd + 0.03366 Mp + 94.3 w/c*w/c - 0.000363 Mp*Mp **Eq. (4.4)**

Table 4.6 R^2, RMSE and MAPE values for density, compressive strength, splitting tensile strength and flexural strength for waste rock (WR)-alccofine concrete

Parameter	**R^2**	**R^2 (adjusted)**	**R^2 (predicted)**	**RMSE**	**MAPE**
Density (Kg/m^3)	86.39	84.49	82.45	20.766	0.657
Compressive strength (MPa)	95.41	94.89	94.15	2.395	3.955
Splitting tensile strength (MPa)	87.82	86.07	81.64	0.084	1.322
Flexural strength (MPa)	94.75	93.37	88.62	0.094	1.243

Table 4.7 ANOVA summary for density, compressive strength, splitting tensile strength and flexural strength of waste rock (WR)-alccofine concrete mixes

Source	DF	Adj MS	F-Value	F-Tabulated	P-Value
Density of WR-alccofine					
Regression	6	136901	45.5	2.29	0.000
Residual	43	21562			
Total	49	-			
Compressive strength of WR-alccofine					
Regression	5	5961.2	182.94	2.29	0.000
Residual	44	286.7			
Total	49				
Splitting tensile strength of WR-alccofine					
Regression	3	0.425991	50.45	3.01	0.000
Residual	21	0.008444			
Total	24				
Flexural strength of WR-alccofine					
Regression	5	0.79592	68.56	3.01	0.000
Residual	19	0.01161			
Total	24				

Table 4.8 Parametric estimates for density, compressive strength, splitting tensile strength and flexural strength for waste rock (WR)-alccofine concrete

Term	Coefficient	SE coefficient	T-Value	T-Tabulated	P-Value
Density of WR-alccofine					
Constant	2567.2	36.3	70.67	2.984	0.000
w/c	-184.3	85.1	-2.17		0.036
Cd	3.281	0.668	4.91		0.000
Mp	9.41	1.81	5.21		0.000
Cd*Cd	-0.0318	0.0109	-2.91		0.006
Mp*Mp	-0.0527	0.0256	-2.06		0.045

Term	Coefficient	SE coefficient	T-Value	T-Tabulated	P-Value
w/c*Mp	-11.07	4.31	-2.57		0.014
Compressive strength of WR -alccofine					
Constant	51.63	2.6	19.86	2.865	0.000
w/c	-48.18	5.76	-8.36		0.000
Cd	1.1215	0.0784	14.3		0.000
Mp	0.3867	0.0483	8		0.000
Cd*Cd	-0.0097	0.00125	-7.79		0.000
Cd*Mp	-0.0058	0.00143	-4.03		0.000
Splitting tensile strength of WR-alccofine					
Constant	4.393	0.187	23.55	2.563	0.000
w/c	-1.581	0.449	-3.52		0.002
Cd	0.00845	0.00132	6.41		0.000
Mp	0.01502	0.00154	9.73		0.000
Flexural strength of WR-alccofine					
Constant	23	2.95	7.79	2.456	0.000
w/c	-81.7	14.9	-5.49		0.000
Cd	0.00964	0.00156	6.19		0.000
Mp	0.03366	0.00577	5.83		0.000
w/c*w/c	94.3	18.6	5.08		0.000
Mp*Mp	-0.0004	0.00017	-2.19		0.041

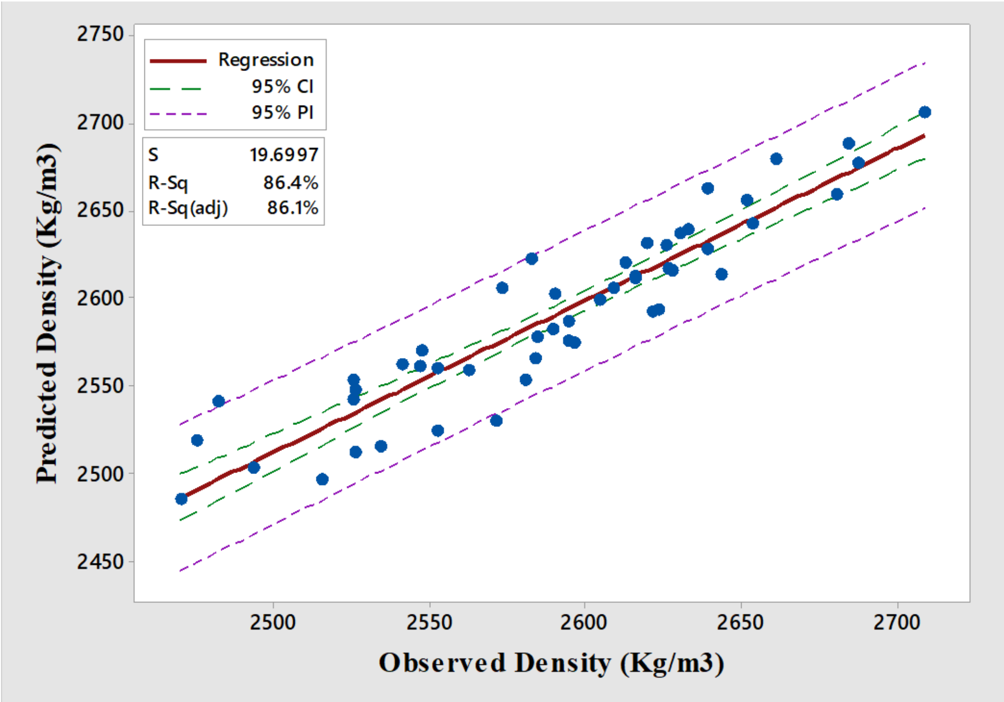


Fig. 4.27 Prediction vs. observed density plot for waste rock (WR)-alccofine concrete

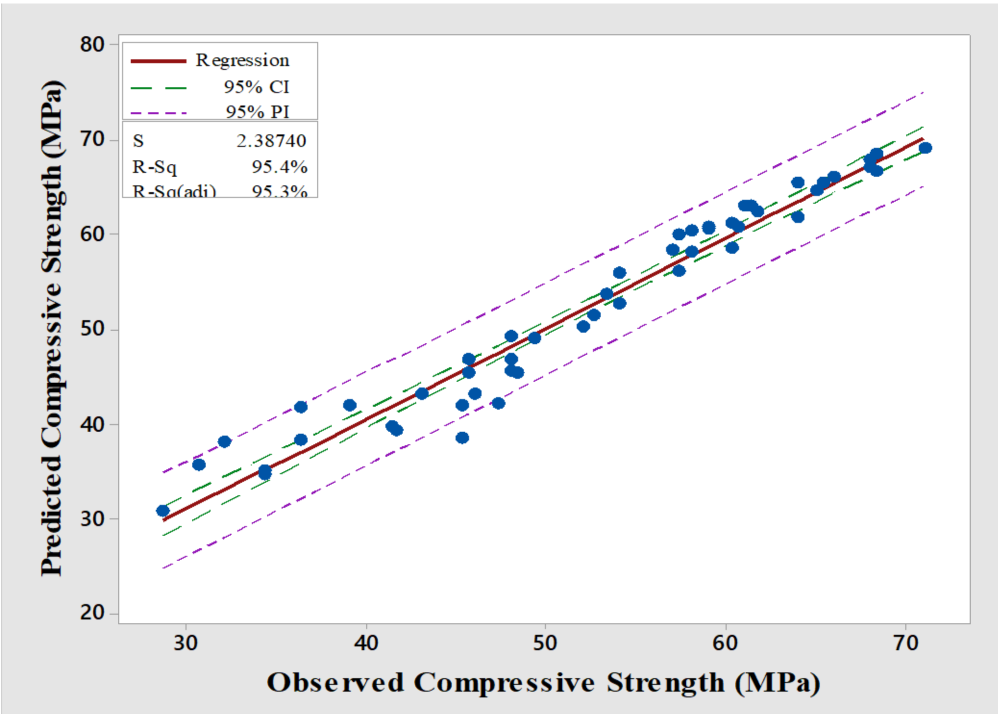


Fig. 4.28 Prediction vs. observed compressive strength plot for waste rock (WR)-alccofine concrete

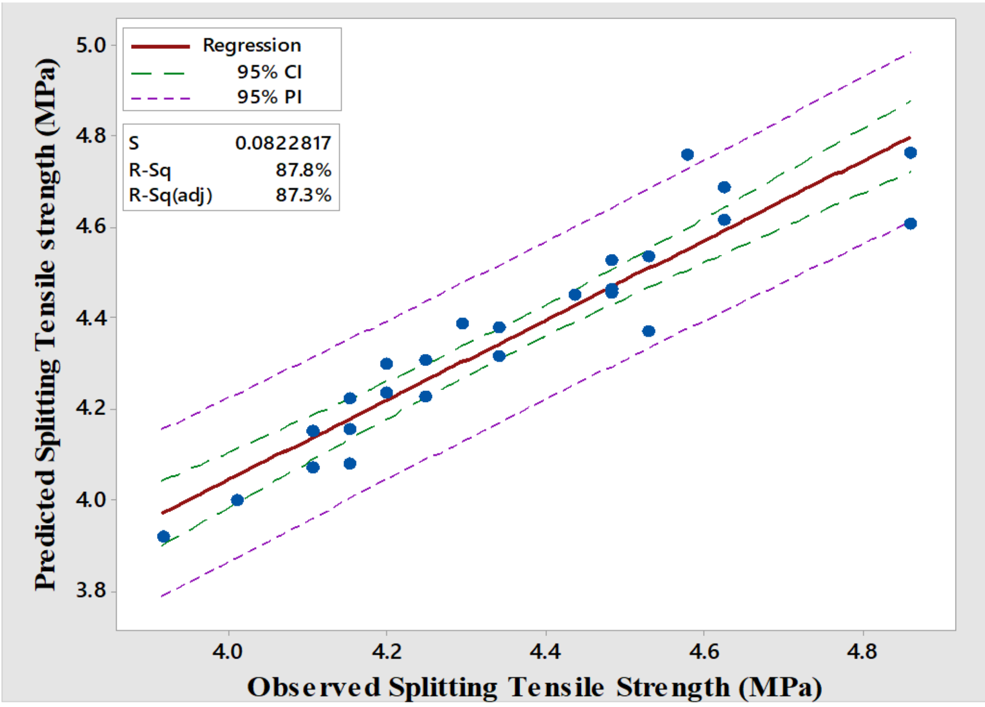


Fig. 4.29 Prediction vs. observed splitting tensile strength plot for waste rock (WR)-alccofine concrete

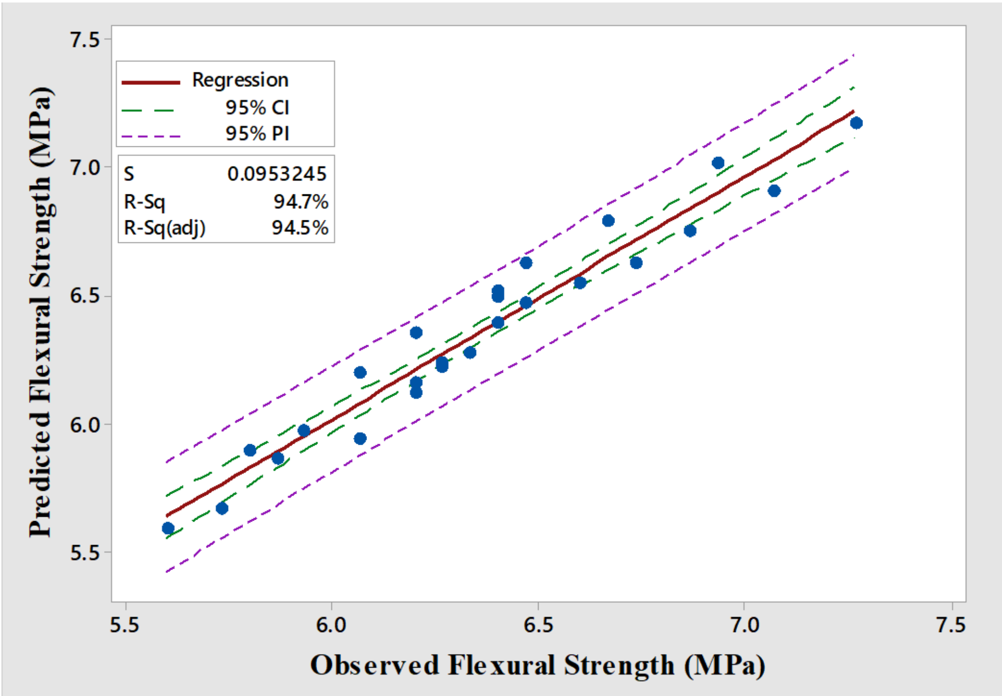


Fig. 4.30 Prediction vs. observed flexural strength plot for waste rock (WR)-alccofine concrete

4.8.2.Prediction analysis for IOT-alccofine concrete

Regression models were developed to predict the density, compressive strength, splitting tensile strength and flexural strength of IOT-alccofine concrete as shown in Table 4.5, by considering the water-cement ratio (w/c), mix percentage (Mp), curing days (Cd) of IOT-alccofine concrete. In the present study, regression models were developed using backward elimination method to eliminate the independent variables which do not influence the dependent variable.

Based on the ANOVA analysis, to find the percentage contribution on input parameters (water-cement ratio (w/c), percentage (%) replacement, curing days (Cd)) on output parameters (density, compressive strength, splitting tensile strength, flexural strength), the F (estimated) value of input parameters is greater than F tabulated value also when the P value of input parameters is less 0.05, then the input parameters are statistically significant within the expected range.

The observed vs. predicted values were obtained using 70% of the data set of respective parameters to develop this model. The majority of observed values were within the predicted ranges. Hence, it is apparent that the model predicts the parameters accurately based on the error percentage which is within the limit of 10%. The plots for observed vs. predicted values for all the parameters are shown in Fig. 4.28, Fig 4.29, Fig 4.30 and Fig 4.31. One outlier point is observed in Fig. 4.30 and Fig. 4.31. To validate the model, 30% of the data were considered and the experimentally measured values and predicted parameters values are compared. The percentage of error is within the range of 10% and hence the model developed can certainly help in the mix design optimization. The analysis of variance (ANOVA) test summary given in Table 4.6 indicates that the model is robust and parametric estimates given in Table 4.7 shows that all the independent variables were significant at 95% confidence level.

Prediction models for density, compressive strength, splitting tensile strength and flexural strength for WR-alccofine concrete are given below:

$$\text{Density (Kg/m}^3) = 2575.2 - 156.3\ w/c + 1.1200\ Cd + 11.120\ Mp - 24.70\ w/c*Mp$$

Eq. (4.5)

Compressive strength (MPa) = -46.3 + 376 w/c + 1.3534 Cd + 1.250 Mp - 488 w/c*w/c - 0.013031 Cd*Cd- 0.00896 Mp*Mp - 1.909 w/c*Mp

Eq. (4.6)

Splitting tensile strength (MPa) = 4.854 - 2.612 w/c + 0.00670 Cd + 0.01185 Mp

Eq. (4.7)

Flexural strength (MPa) = 7.794 - 5.917 w/c + 0.01247 Cd + 0.01198 Mp **Eq. (4.8)**

Table 4.9 Prediction models for density, compressive strength, splitting tensile strength and flexural strength for iron ore tailings (IOT) -alccofine concrete

Parameter	R^2	R^2 (adjusted)	R^2 (predicted)	RMSE	MAPE
Density (Kg/m^3)	95.70	95.6	95.1	7.664	0.254
Compressive strength (MPa)	98.29	98.3	97.6	1.770	3.326
Splitting tensile strength (MPa)	73.00	71.8	70.5	0.118	2.059
Flexural strength (MPa)	77.21	76.2	74.4	0.170	2.160

Table 4.10 ANOVA summary for density, compressive strength, splitting tensile strength and flexural strength of IOT-alccofine concrete mixes

Source	DF	Adj MS	F-Value	F-Tabulated	P-Value
Density of IOT-alccofine					
Regression	4	16177.6	247.91	2.56	0.00
Residual	45	65.3			
Total	49	-			
Compressive strength of IOT-alccofine					
Regression	7	1233.77	328.24	2.2	0.00
Residual	40	3.76			
Total	47				
Splitting tensile strength of IOT-alccofine					
Regression	7	1233.77	328.24	2.2	0.00
Residual	40	3.76			
Total	47				

Source	DF	Adj MS	F-Value	F-Tabulated	P-Value
Density of IOT-alccofine					
Flexural strength of IOT-alccofine					
Regression	7	1233.77	328.24	2.2	0.00
Residual	40	3.76			
Total	47				

Table 4.11 Parametric estimates for density, compressive strength, splitting tensile strength and flexural strength for iron ore tailings (IOT) -alccofine concrete

Term	Coefficient	SE coefficient	T-Value	T-Tabulated	P-Value
Density of IOT-alccofine					
Constant	2575.2	18.9	136.53	2.776	0.000
w/c	-156.3	46.5	-3.36		0.002
CD	1.12	0.0544	20.58		0.000
MP	11.12	0.943	11.79		0.000
w/c*MP	-24.7	2.3	-10.73		0.000
Compressive strength of IOT-alccofine					
Constant	-46.3	38.8	-1.19	2.365	0.240
w/c	376	191	1.97		0.050
CD	1.3534	0.0592	22.85		0.000
MP	1.25	0.315	3.97		0.000
w/c*w/c	-488	237	-2.05		0.047
CD*CD	-0.013031	0.000978	-13.33		0.000
MP*MP	-0.00896	0.0028	-3.2		0.003
w/c*MP	-1.909	0.613	-3.11		0.003
Splitting tensile strength of IOT-alccofine					
Constant	4.854	0.273	17.76	3.182	0.000
w/c	-2.612	0.645	-4.05		0.001
CD	0.0067	0.00185	3.62		0.002
MP	0.01185	0.00216	5.49		0.000
Flexural strength of IOT-alccofine					
Constant	7.794	0.403	19.33	3.182	0.000
w/c	-5.917	0.952	-6.22		0.000
CD	0.01247	0.00273	4.57		0.000
MP	0.01198	0.00318	3.76		0.001

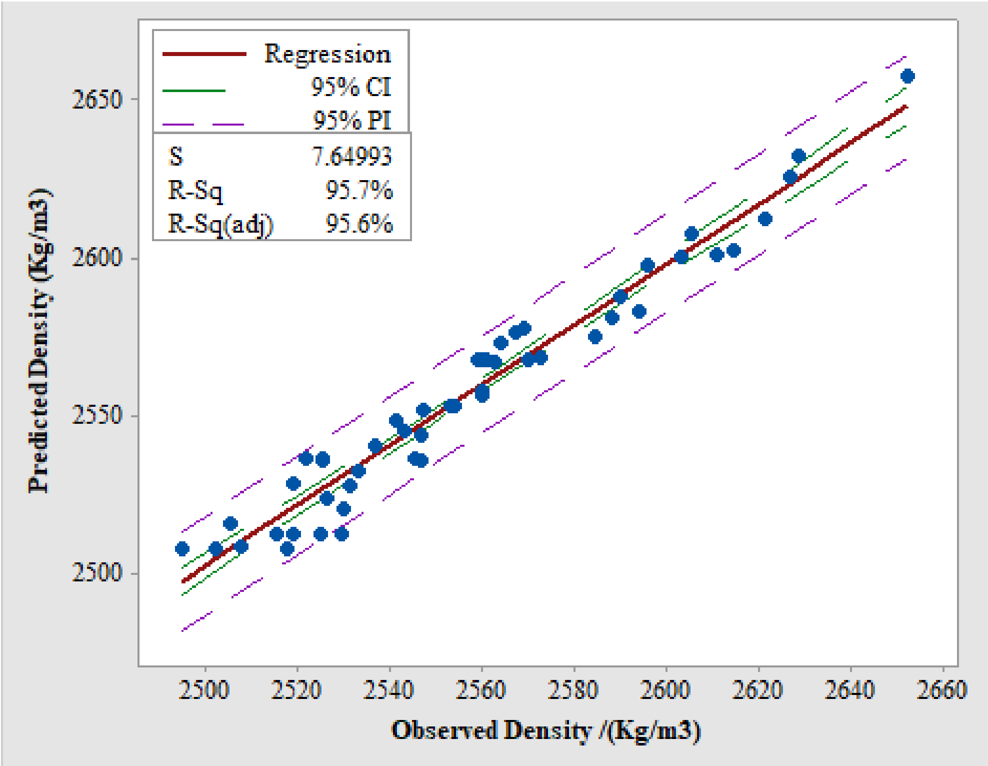


Fig. 4.31 Prediction vs. observed density plot for IOT-alccofine concrete

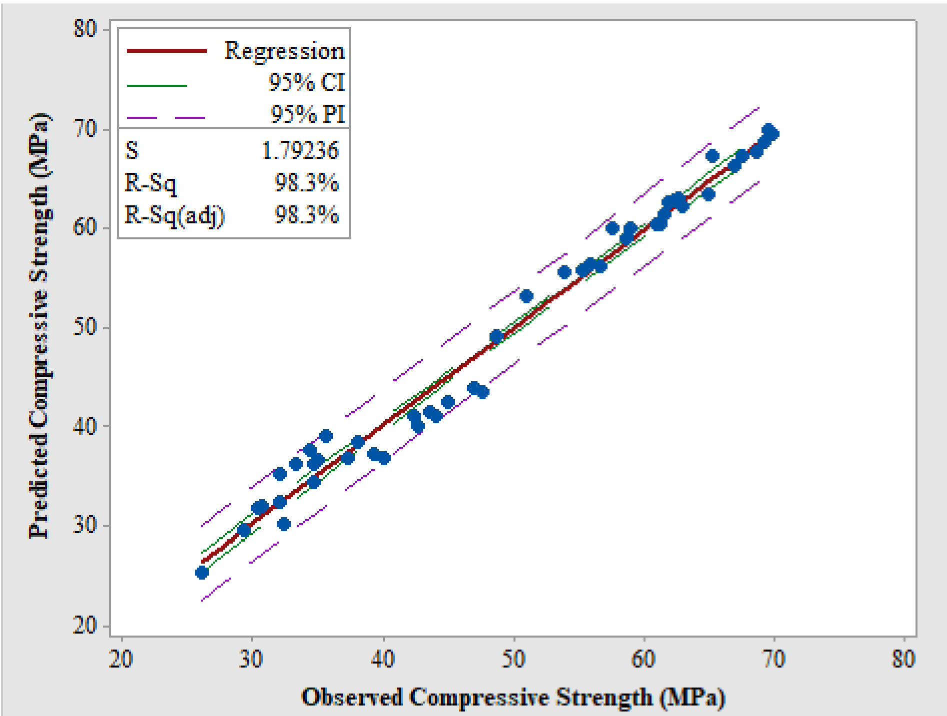


Fig. 4.32 Prediction vs. observed compressive strength plot for IOT-alccofine concrete

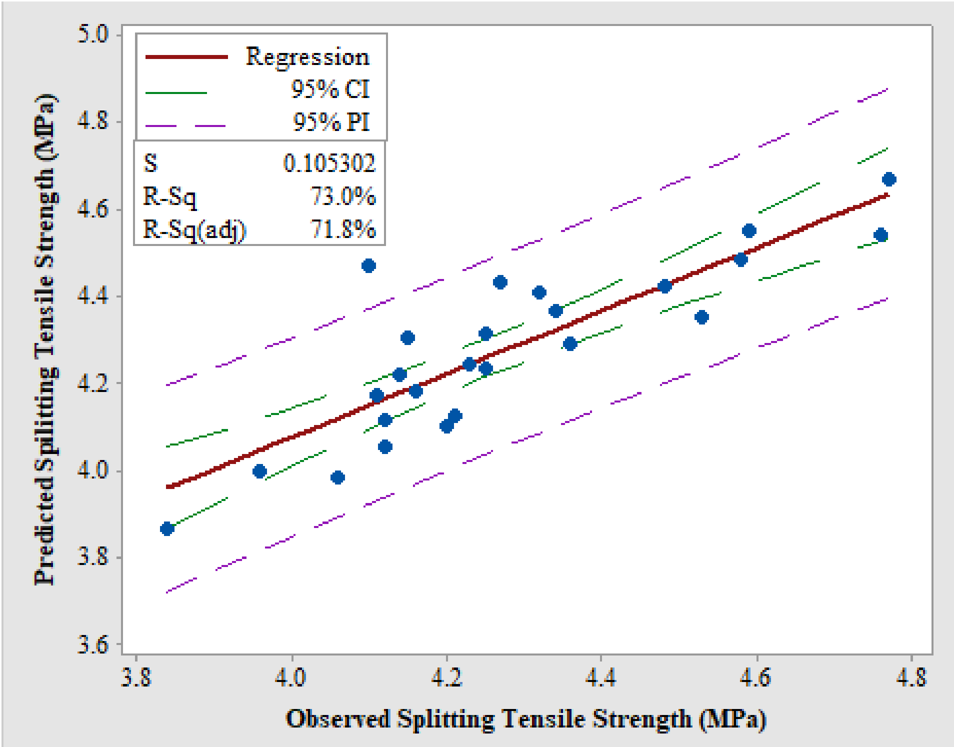


Fig. 4.33 Prediction vs. observed splitting tensile strength plot for IOT-alccofine concrete

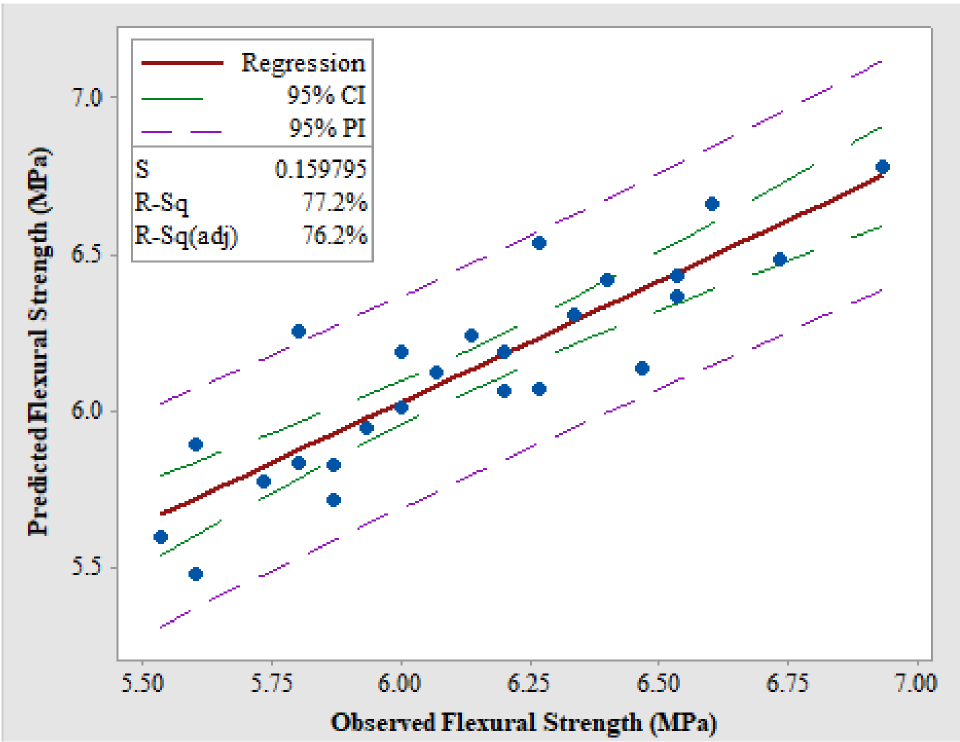


Fig. 4.34 Prediction vs. observed flexural strength plot for IOT-alccofine concrete

4.8.3.Prediction analysis for EP concrete

Regression models were developed to predict the density, compressive strength, splitting tensile strength and flexural strength of EP concrete as shown in Table 4.8, by considering the water-cement ratio (w/c), mix percentage (Mp), curing days (Cd) of EP concrete. Regression models were developed using backward elimination method to eliminate the independent variables which do not influence the dependent variable.

Based on the ANOVA analysis, to find the percentage contribution on input parameters (water-cement ratio (w/c), percentage (%) replacement, curing days (Cd)) on output parameters (density, compressive strength, splitting tensile strength, flexural strength), the F (estimated) value of input parameters is greater than F tabulated value also when the P value of input parameters is less 0.05, then the input parameters are statistically significant within the expected range.

The observed versus predicted values were obtained using 70% of the data set of respective parameters to develop this model. The majority of observed values were within the predicted ranges. Hence, it is apparent that the model predicts the parameters accurately based on the error % which is within the limit of 10%. The observed versus predicted values for density, compressive, splitting tensile and flexural strength are shown in Fig. 4.32, Fig. 4.33, Fig. 4.34 and Fig. 4.35. One outlier point in Fig. 4.32 and four points in Fig. 4.33 were observed.

To validate the model, 30% of the data were considered and comparison is done between the experimentally measured values and predicted parameters values. The percentage of error is within the range of 10% and hence the model developed can certainly help in the mix design optimization.

The analysis of variance (ANOVA) test summary given in Table 4.9 indicates that the model is robust and parametric estimates given in Table 4.10 shows that all the independent variables were significant at 95% confidence level.

Prediction models for density, compressive strength, splitting tensile strength and flexural strength for WR-alccofine concrete are given below:

Density (Kg/m^3) = 2598.72 + 0.316 Cd - 35.34 Mp + 1.363 Mp*Mp **Eq. (4.9)**

Compressive strength (MPa) = 37.52 - 29.8 w/c + 1.4171 Cd - 0.0881Mp - 0.0160 Cd*Cd **Eq. (4.10)**

Splitting tensile strength (MPa) = 4.092 - 1.510 w/c + 0.00719 Cd - 0.02705 Mp **Eq. (4.11)**

Flexural strength (MPa) = 6.418 - 3.733 w/c + 0.01571 Cd + 0.1844 Mp - 0.01524 Mp*Mp **Eq. (4.12)**

Table 4.12 Prediction models for density, compressive strength, splitting tensile strength and flexural strength for expanded perlite (EP) concrete

Parameter	**R^2**	**R^2 (adjusted)**	**R^2 (predicted)**	**RMSE**	**MAPE**
Density (Kg/m^3)	91.30	90.83	90.22	19.56	0.639
Compressive strength (MPa)	92.43	91.88	91.08	2.395	3.955
Splitting tensile strength (MPa)	67.10	63.31	56.28	0.084	1.322
Flexural strength (MPa)	90.30	88.75	86.31	0.094	1.243

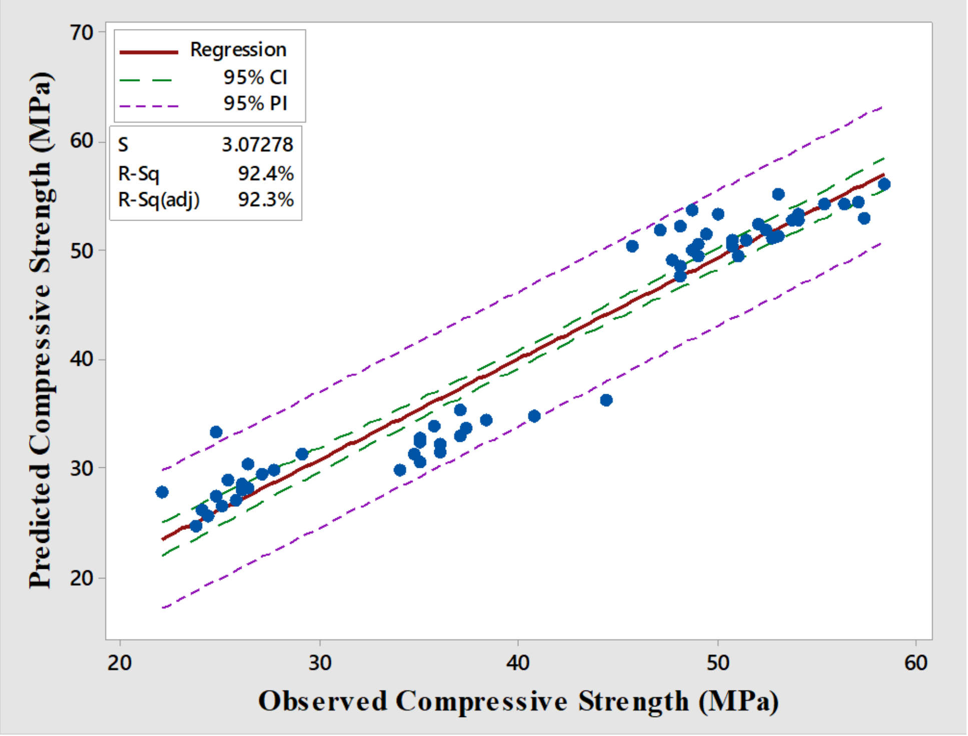
Table 4.13 ANOVA summary for density, compressive strength, splitting tensile strength and flexural strength of expanded perlite (EP) concrete mixes

Source	**DF**	**Adj MS**	**F-Value**	**F-Tabulated**	**P-Value**
Compressive strength of EP concrete					
Regression	3	1677.52	128.27	1.671	0.000
Residual	38	13.08			
Total	41				

Splitting tensile strength of EP concrete					
Regression	4	0.63282	36.14	1.725	0.000
Residual	16	0.01751			
Total	20				
Flexural strength of EP concrete					
Regression	5	0.79592	68.56	1.711	0.000
Residual	19	0.01161			
Total	24				

Table 4.14 Parametric estimates for density, compressive strength, splitting tensile strength and flexural strength for expanded perlite (EP) concrete

Term	Coefficient	SE coefficient	T-Value	T-Tabulated	P- Value
Density of EP concrete					
Constant	2598.72	7.7	337.43	1.22	0.00
Cd	0.316	0.154	2.06		0.045
Mp	-35.34	3.22	-10.96		0.00
Mp*Mp	1.363	0.309	4.41		0.00
Compressive strength of EP concrete					
Constant	37.52	4.28	8.76	2.53	0.00
w/c	-29.8	10.4	-2.87		0.006
Cd	1.4171	0.0897	15.8		0.000
Mp	0.0881	0.03	2.94		0.005
Cd*Cd	-0.01609	0.00147	-10.87		0.00
Splitting tensile strength of IOT-alccofine					
Constant	4.092	0.217	18.88	3.54	0.000
w/c	-1.51	0.511	-2.95		0.007
Cd	0.00719	0.00149	4.83		0.000
Mp	-0.02705	0.0059	-4.58		0.000
Flexural strength of EP concrete					
Constant	6.418	0.227	28.24	2.33	0.000
w/c	-3.733	0.532	-7.02		0.000
Cd	0.01571	0.0015	10.13		0.000
Mp	0.1844	0.0217	8.51		0.000
Mp*Mp	-0.0152	0.002	-7.34		0.000



.

Fig. 4.35 Prediction vs. observed density plot for expanded perlite (EP) concrete

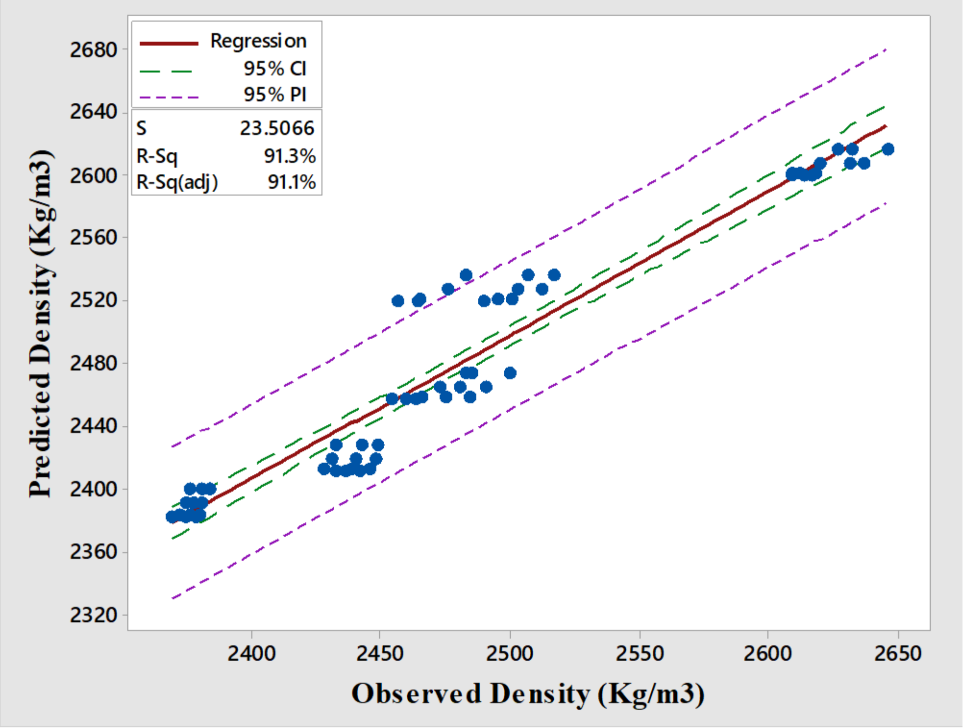


Fig. 4.36 Prediction vs. observed compressive strength plot for expanded perlite (EP) concrete

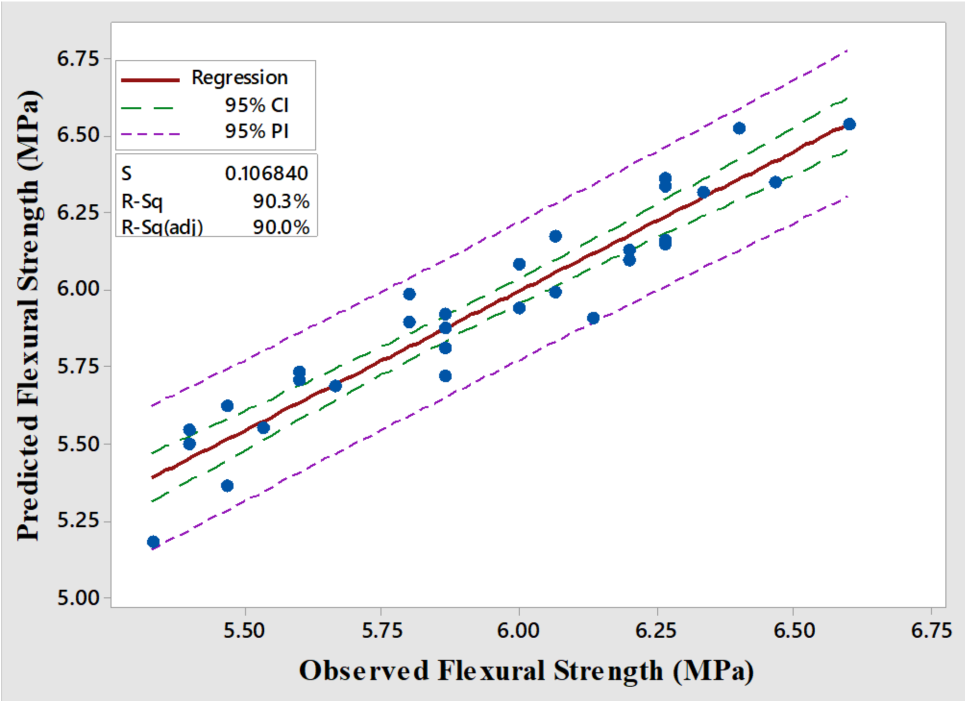


Fig. 4.37 Prediction vs. observed splitting tensile strength plot for expanded perlite (EP) concrete

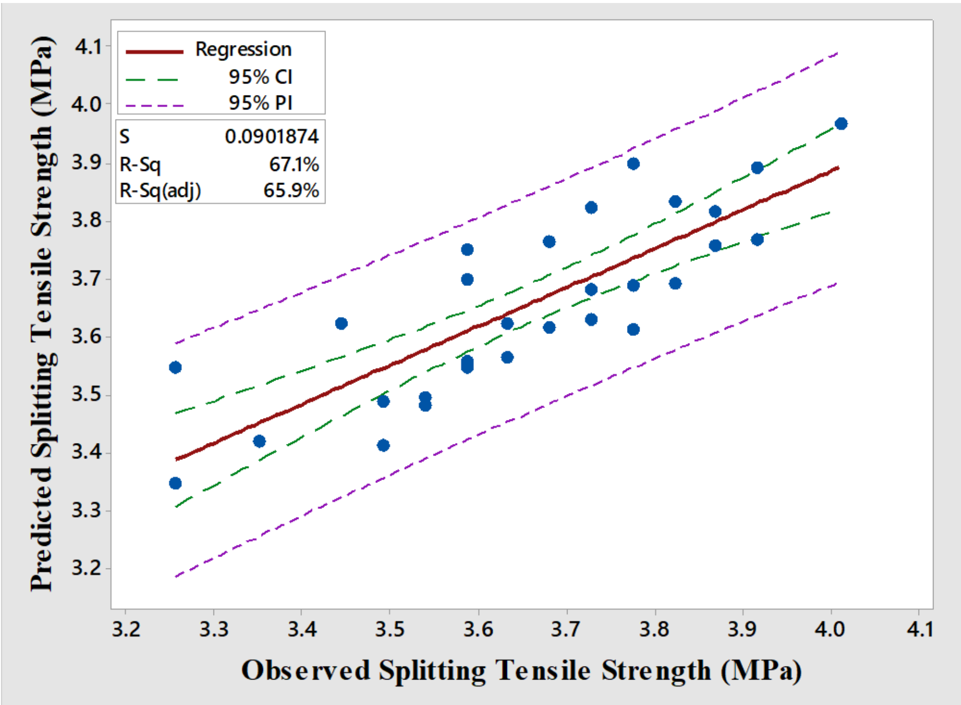


Fig. 4.38 Prediction vs. observed flexural strength plot for expanded perlite (EP) concrete

4.9 SUMMARY

In this chapter, the experimental investigation was carried out for materials viz., iron ore waste rock as coarse aggregates, iron ore tailing as fine aggregates, expanded perlite as fine aggregates with alccofine as a binder material in concrete. Various mix proportions were considered based on the mix design and their properties were determined in fresh and hardened state viz., workability, compressive strength, splitting tensile strength, flexural strength. Durability of the concrete specimen was determined by rapid chloride permeability test (RCPT). Regression models were developed and cost analysis of concrete with the mentioned marginal materials were calculated and presented in Chapter 4.

CHAPTER-5

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results obtained from the experimental studies, the following conclusions are drawn:

5.1.1 Material Properties:

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

ii. Chemical composition of the materials i.e., WR, IOT and alccofine were determined using X-ray fluorescence (XRF) and it was observed that, the materials consists of major elements viz., high percentage of Silicon dioxide (SiO_2), Iron oxide (Fe_2O_3), Aluminium oxide (Al_2O_3), Calcium oxide (CaO).

5.1.2 Strength properties of WR-concrete and IOT-concrete

i. ***Workability:*** With reference to the control concrete mix, workability decreased with increase in WR percentage from 10% to 50% with 10% intervals. This may be due to the shape of aggregates which are angular. In case of IOT, workability decreased with increase in IOT replacement from 10% to 50% with 10% intervals due to the high surface area which absorbs more water content. Superplasticizer was added as water reducing agent to increase the workability of concrete and hence, WR and IOT concrete resulted in slump values between 25 to 50 mm.

ii. ***Compressive strength:*** In WR concrete, strength increased with increased in WR quantity from 10% to 50% with 10% intervals with reference to control concrete.

Strength increased by 26.09%, 24.79%, and 23.29% for 40%, 30% and 20% WR replacement as coarse aggregates in concrete for 0.35, 0.40 and 0.45 w/c and for 28 days cured specimens. In case of IOT concrete, strength increased with increase in IOT content upto 30%, 20%, 10% and then the strength decreased with increase in IOT content for 0.35, 0.40 and 0.45 w/c. This is due to the high specific gravity of IOT in concrete.

iii. ***Splitting tensile and flexural strength:*** Similarly, splitting tensile strength and flexural strength resulted in increasing strength upto optimum percentages as in the case of compressive strength in both the cases i.e., WR and IOT concrete. Flexural strength obtained satisfies the mix design criteria.

iv. Based on the results, strength obtained were satisfactory with WR and IOT as coarse and fine aggregates respectively. But due to the water absorption capacity of these marginal materials, alccofine is used as a binder replacement to enhance the strength properties of WR and IOT concrete.

5.1.3 Strength properties of WR-alccofine and IOT-alccofine concrete

i. ***Workability:*** With the addition of 10% alccofine as binder material, slump values increased with increasing percentages of WR in concrete compared to the slump test of WR concrete. Similarly in the case of IOT as fine aggregates, slump value increased with increase in IOT replacement. WR and IOT concrete with alccofine resulted in slump values between 25 to 50 mm.

ii. ***Density:*** Due to the high specific gravity of WR and IOT concrete, the density of concrete with WR-alccofine and IOT-alccofine increased making it a heavy density concrete. Density ranged from around 2450-2700 MPa in both the concrete mixes.

iii. ***Compressive strength:*** In WR-alccofine concrete, strength increased with increased in WR quantity from 10% to 50% with 10% intervals with reference to control concrete. Maximum strength of 68.00 and 75.33 MPa was obtained for 28 and 56 days cured specimens for 0.35 w/c at 50% WR replacement. The strength decreased with increase in w/c from 0.35 to 0.40 and 0.45 and inturn the optimum percentage decreased by 40% and 30% WR replacement. In case of IOT-alccofine concrete, optimum percentage was observed at 40% IOT replacement and the maximum strength obtained is 63 and 70 MPa for 28 and 56 cured specimens. This strength observed is maximum compared to IOT concrete without alccofine.

iv. ***Splitting tensile and flexural strength:*** Similarly, splitting tensile strength and flexural strength resulted in increasing strength upto optimum percentages as in the case of compressive strength in both the cases i.e., WR-alccofine and IOT-alccofine concrete. Flexural strength obtained is greater than 4.50 MPa which satisfies the design mix criteria. The range of flexural strength was 5.60 to 7.33 MPa.

v. WR-alccofine and IOT-alccofine concrete mixes are high dense concrete. These can be practically applicable in roller compacted concrete, atomic power plants, reinforced concrete, etc.

vi. Due to the high density of WR-alccofine and IOT-alccofine concrete, expanded perlite was added to reduce the density of concrete. To obtain low weight concrete, EP is used as a density controller.

5.1.4 Strength properties of EP-concrete:

i. In this case, the optimum percentages obtained from WR-alccofine concrete and IOT-alccofine concrete was considered for their respective w/c as control mix concrete. To this EP is added in varying percentages from 2.5% to 10% with 2.5% intervals.

ii. ***Workability:*** The workability of concrete decreased with increase in expanded perlite (EP) percentage. For varying water-cement ratio, the workability of concrete increased with reference to the control concrete mix. This is due to the high water absorption and porous nature of EP concrete.

iii. ***Density and compressive strength:*** The density and compressive strength decreased with increase in dosage of EP for each w/c mix of concrete samples, for

0.35 w/c the compressive strength is 55.53 MPa, i.e., 5% decrease with reference to the control concrete at 5% EP dosage level. Similarly, for 0.40 and 0.45 w/c, 5% and 8% decrease resulted at 5% EP dosage respectively at 56 days curing.

iv. ***Splitting tensile and flexural strength:*** The splitting tensile strength and flexural strength of EP concrete depicted decrease in strength similar to the compressive strength dosage levels with reference to the w/c.

v. Strength values obtained for the EP mixes reduced with comparison to the control mix but have attained the target strength required for M40 grade and are comparatively higher than the WR and IOT concrete mixes. EP concrete can be used as a light weight concrete on pavements as it has good thermal properties. Other application includes, light weight mortars, ceiling tiles and as filter aids due to its acoustic, fire resistance and insulator properties.

5.1.5 Statistical Analysis

Regression models were developed for each of the properties tested in laboratory scale. The equations developed were found to be robust and statistically fit for prediction of the properties. R^2 values obtained for WR-alccofine, IOT-alccofine and EP concrete were greater than 93for all the parameters considered in the research study. The Root Mean Square Error (RMSE) and MAPE values for all the above cases were found to be within the range.

5.2 Recommendations/ Future Work

i. Based on the present experimental data, pavement design as per IS standards can be designed and a pilot road stretch i.e., concrete pavement with marginal materials like iron ore tailings, iron ore waste rock, expanded perlite with alccofine as binder content as per mix design and the performance of the pavement can be monitored.

ii. Experimental investigations can be carried out with WR and IOT as coarse and fine aggregates with additives such as metakaoline, fly ash, GGBS, etc., to determine its properties in concrete and application in the construction industry.

iii. Leachability tests to be conducted on the marginal materials used in concrete.

iv. WR can be used as aggregate replacement in bitumen concrete mixes and determine its properties for applications in bitumen pavements.

v. Thermal conductivity of expanded perlite in concrete can be investigated and its application on concrete pavements.

REFERENCES

REFERENCES

Andre, H., Urs, E. and Thomas, M. (1999), “Fly ash from cellulose industry as secondary raw material in autoclaved aerated concrete”, *J.Cement Concrete Res.,* 29(3), 297-302.

Ann, K. Y., Moon, H. Y., Kim, Y. B., and Ryou, J. (2008). “Durability of recycled aggregate concrete using pozzolanic materials.” *Waste Manag*., 28(6), 993–999.

Arora, S., and Singh, S. P. (2016). “Analysis of flexural fatigue failure of concrete made with 100% Coarse Recycled Concrete Aggregates.” *Constr. Build. Mater*., 102, 782–791.

Batayneh, M., Marie, I., and Asi, I. (2007). “Use of selected waste materials in concrete mixes.” 27, 1870–1876.

Belhadj, B., Bederina, M., Benguettache, K., and Queneudec, M. (2014). “Effect of the type of sand on the fracture and mechanical properties of sand concrete.” *Adv. Concr. Constr.*, 2(1), 13–27.

Binici, H., Shah, T., Aksogan, O., and Kaplan, H. (2008). “Durability of concrete made with granite and marble as recycle aggregates.” *J. Mater. Process. Technol.,* 208(1–3), 299–308.

Bureau of Indian Standards (BIS). 53 grade ordinary Portland cement specification. IS: 12269.New Delhi, India; 2013.

Bureau of Indian Standards (BIS). Concrete Mix Proportioning-Guidelines. IS: 10262: New Delhi, India; 2009.

Bureau of Indian Standards (BIS). Concrete Mix Proportioning-Guidelines. IS: 516: New Delhi, India; 1959.

Bureau of Indian Standards (BIS). Methods of sampling and analysis of concrete. IS: 1199: New Delhi, India; 1959.

Bureau of Indian Standards (BIS). Specification for coarse and fine aggregates from natural sources for concrete. IS: 383: New Delhi, India; 1970.

Bureau of Indian Standards (BIS). Splitting tensile strength of concrete –Method of test. IS: 5816: New Delhi, India; 1999.

Cai, J.W., Zhang, S.B., Hou, G.X. and Wang, C.M. (2009), "Effects of ferrous mill tailings as aggregates on workability and strength of concrete", J. Wuhan Univ.Technol., 31(7), 104-107.

Chakravarthy, S.M. and Kadiyalli, L.R. (1989), "Economics of concrete roads", Ind. Concrete J., 63, 239-243

Chandar, K. R., Gayana, B. C., and Sainath, V. (2016). "Experimental investigation for partial replacement of fine aggregates in concrete with sandstone." *Adv. Concr. Constr.*, 4(4), 243–261.

Chandra, S. and Berntsson, L. (2002), Lightweight Aggregate Concrete, Noyes Publications/William Andrew Publishing, NY.

Chávez-Ulloa, E., Camacho-Chab, R., Sosa-Baz, M., Castro-Borges, P., and Pérez-López, T. (2013). "Corrosion process of reinforced concrete by carbonation in a natural environment and an accelerated test chamber." *Int. J. Electrochem. Sci.*, 8(7), 9015–9029.

Das, B., Reddy, P. S. R., and Misra, V. N. (2002). "Recovery of Iron Values From Tailing Dumps Adopting Hydrocyclone and Magnetic Separation Techniques." *Australas. Inst. Min. Metall. Publ. Ser.*, 285–289.

Das, S. K., Kumar, S., and Ramachandrarao, P. (2000). "Exploitation of iron ore tailing for the development of ceramic tiles." *Waste Manag.*, 20(8), 725–729.

Duan, P., Yan, C., Zhou, W., and Ren, D. (2016). "Fresh properties, compressive strength and microstructure of fly ash geopolymer paste blended with iron ore tailing under thermal cycle." *Constr. Build. Mater.*, 118, 76–88.

Dudka, S., and Adriano, D. C. (1997). “Environmental impacts of metal ore mining and processing: A review.” *J. Environ. Qual.*, 26(3), 590–602.

Fan, J., Cao, D., Jing, Z., Zhang, Y., Pu, L., and Jing, Y. (2014). “Synthesis and microstructure analysis of autoclaved aerated concrete with carbide slag addition.” *J. Wuhan Univ. Technol. Mater. Sci. Ed.*, 29(5), 1005–1010.

Fontes, W. C., Mendes, J. C., Silva, S. N. Da, and Peixoto, R. A. F. (2016). “Mortars for laying and coating produced with iron ore tailings from tailing dams.” *Constr. Build. Mater.*, 112, 988–995.

Gül, R., Okuyucu, E., Türkmen, İ., and Aydin, A. C. (2007). “Thermo-mechanical properties of fiber reinforced raw perlite concrete.” 61, 5145–5149.

Huang, X., Ranade, R., and Li, V. C. (2012). “Feasibility Study of Developing Green ECC Using Iron Ore Tailings (IOTs) Powder as Cement Replacement.” *J. Mater. Civ. Eng.*,120901010105008.

Huang, X., Ranade, R., Li, V. C., and ASCE, F. (2013). “Feasibility Study of Developing Green ECC Using Iron Ore Tailings Powder as Cement Replacement.” *J. Mater. Civ. Eng*. 25, 923–931.

Ismail, Z. Z., and Al-hashmi, E. A. (2008). “Use of waste plastic in concrete mixture as aggregate replacement.” 28, 2041–2047.

Juwarkar, A.A., Singh, S.K., Dubay, K. and Nimje, M. (2003), “Reclamation of iron mine spoil dumps using integrated biotechnological approach”, Proceedings of the National Seminar on Status of Environmental Management in Mining Industry, BHU, 197-212.

Karra, R. C., Raghunandan, M. E., and Manjunath, B. (2016). “Partial replacement of fine aggregates with laterite in GGBS-blended-concrete.” *Adv. Concr. Constr.*, 4(3), 221–230.

Kumar, S., Gupta, R. C., Shrivastava, S., Csetenyi, L., and Thomas, B. S. (2016). "Preliminary study on the use of quartz sandstone as a partial replacement of coarse aggregate in concrete based on clay content, morphology and compressive strength of combined gradation." *Constr. Build. Mater.*, 107, 103–108.

Kurama, H., Topçu, I. B., and Karakurt, C. (2009). "Properties of the autoclaved aerated concrete produced from coal bottom ash." *J. Mater. Process. Technol.*, 209(2), 767–773.

Li, C., Sun, H., Yi, Z., and Li, L. (2010). "Innovative methodology for comprehensive utilization of iron ore tailings. Part 2: The residues after iron recovery from iron ore tailings to prepare cementitious material." *J. Hazard. Mater.*, 174(1–3), 78–83.

Li, D., Ni, W., Zhang, J., Wu, H., and Zhang, Y. (2011). "Phase transformation of iron ore tailings during autoclaved curing." *Kuei Suan Jen Hsueh Pao/Journal Chinese Ceram. Soc.*, 39(4), 708–713.

Li, M., and Li, V. C. (2009). "Influence of material ductility on performance of concrete repair." *ACI Mater. J.,* 106(5), 419–428.

Licskó, I., Lois, L., and Szebényi, G. (1999). Tailings as a source of environmental pollution. *Water Sci. Technol*.

Lima, C., Caggiano, A., Faella, C., Martinelli, E., Pepe, M., and Realfonzo, R. (2013). "Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash." *Constr. Build. Mater.,* 47, 547–559.

Liwu, M., and Min, D. (2006). "Thermal behavior of cement matrix with high-volume mineral admixtures at early hydration age." *Cem. Concr. Res.*, 36(10), 1992–1998.

Ma, B. guo, Cai, L. xiong, Li, X. guo, and Jian, S. wei. (2015). "Utilization of iron tailings as substitute in autoclaved aerated concrete: Physico-mechanical and microstructure of hydration products." *J. Clean. Prod.*, 127, 162–171.

Maiti, S. K., Nandhini, S., and Das, M. (2005). “Accumulation of metals by naturally growing herbaceous and tree species in iron ore tailings.” *Int. J. Environ. Stud*., 62(5), 593–603.

Meagher, T., Shanahan, N., Buidens, D., Riding, K. A., and Zayed, A. (2015). “Effects of chloride and chloride-free accelerators combined with typical admixtures on the early-age cracking risk of concrete repair slabs.” Constr. Build. Mater., 94, 270–279.

Mindess, S., Young, J. F., and Darwin, D. (2003). Concrete. 2nd Ed., Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Mininstry of Mines, Annual Report, 2018-19. Last accessed Dec 2019.

Mirza, W. H., and Al-Noury, S. I. (1986). “Utilisation of Saudi sands for aerated concrete production.” *Int. J. Cem. Compos. Light. Concr.*, 8(2), 81–85.

Moreno, L., and Neretnieks, I. (2006). “Long-term environmental impact of tailings deposits.” *Hydrometallurgy*, 83(1–4), 176–183.

MORTH 2012A: www.morth.nic.in/Annual Report 2011-12

Mostafa, N. Y. (2005). “Influence of air-cooled slag on physicochemical properties of autoclaved aerated concrete.” *Cem. Concr. Res.*, 35(7), 1349–1357.

Naik, T. R. (2008). “Sustainability of concrete construction.” *Pract. Period. Struct. Des. Constr.*, 13(2), 98–103.

Narendra Reddy, A., and Meena, T. (2015). “A study on compressive behavior of ternary blended concrete incorporating alccofine”. *Materials today: Proceedings*. 5(5).

OGD PMU Team (2018). “Production of iron ore in India from 2000-01 to 2015-16.”

Oktay, H., Yumrutas, R., and Akpolat, A. (2015a). “Mechanical and thermophysical properties of lightweight aggregate concretes.” *Constr. Build. Mater.*, 96, 217–225.

Oktay, H., Yumrutaş, R., and Akpolat, A. (2015b). "Mechanical and thermophysical properties of lightweight aggregate concretes." *Constr. Build. Mater.*, 96, 217–225.

Omar, O. M., Abd Elhameed, G. D., Sherif, M. a., and Mohamadien, H. a. (2012). "Influence of limestone waste as partial replacement material for sand and marble powder in concrete properties." *HBRC J.*, 8(3), 193–203.

Park, T. (2003). "Application of construction and building debris as base and subbase materials in rigid pavement" *J. Transp. Eng.*, 129, 558–563.

Parveen., Dhirendra, Singhal., M, Talha, Junaid., Bharat, Bhushan, Jindal. and Ankur, Mehta. (2018). "Mechanical and microstructural properties of fly ash based geopolymer concrete incorporating alccofine at ambient curing" *Construction and Building Materials.*180: 298-307.

Rajesh Kumar, B., Vardhan, H., Govindaraj, M., and Saraswathi, P. S. (2013). "Artificial neural network model for prediction of rock properties from sound level produced during drilling." *Geomech. Geoengin*., 8(1), 53–61.

Ramanaidou, E.R. and Wells, M.A. (2014), Sedimentary Hosted Iron Ore, Eds. Holland, H.D. and Turekian, K.K., Treatise on Geochemistry, Second Edition,Elsevier, Oxford.

Ravikumar, C.M., Kumar, A., Prashanth, M.H. and Reddy, D.V. (2012), "Experimental studies on iron ore tailings based interlocking paver blocks", Int. J. Earth Sci.Eng., 5(3), 501-504

Saleh Ahari, R., Erdem, T. K., and Ramyar, K. (2015). "Permeability properties of self-consolidating concrete containing various supplementary cementitious materials." *Constr. Build. Mater.*, 79, 326–336.

Sastry, V.R. and Ram Chandar, K. (2013), "Dump stability analysis of an open cast coal mining project", *Min. Eng. J.*, 15(1), 16-23

Saxena, S., Kumar, M. and Singh, N. (2018), “Effect of alccofine powder on the properties of Pond fly ash based Geopolymer mortar under different conditions”, *Journal of EnvironmentalTechnology and Innovation,* 9, 232-242.

Sengul, O., Azizi, S., Karaosmanoglu, F., and Tasdemir, M. A. (2011). “Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete.” *Energy Build.,* 43(2–3), 671–676.

Shaikh, F., Kerai, S., and Kerai, S. (2015). “Effect of micro-silica on mechanical and durability properties of high volume fly ash recycled aggregate concretes (HVFA-RAC).” *Adv. Concr. Constr.,* 3(4), 317–331.

Shettima, A. U., Hussin, M. W., Ahmad, Y., and Mirza, J. (2016). “Evaluation of iron ore tailings as replacement for fine aggregate in concrete.” *Constr. Build. Mater.,* 120, 72–79.

Shetty, K. K., and Nayak, G. (2014). “Effect of red mud and iron ore tailings on the strength of self- compacting concrete.” *Eur. Scientif. J.,* 10(21), 168–176.

Siddique, R. (2014). “Utilization of industrial by-products in concrete.” *Procedia Eng.,* 95, 335–347.

Silva, F. L. Da, Araújo, F. G. S., Teixeira, M. P., Gomes, R. C., and Krüger, F. L. Von. (2014). “Study of the recovery and recycling of tailings from the concentration of iron ore for the production of ceramic.” *Ceram. Int.,* 40, 16085–16089.

Sirkeci, A. A., Gül, A., Bulut, G., Arslan, F., Onal, G., and Yuce, A. E. (2006). “Recovery of co, ni, and cu from the tailings of divrigi iron ore concentrator.” *Miner. Process. Extr. Metall. Rev.,* 27(2), 131–141.

Skarzynska, K. M. (1995). “Reuse of coal mining wastes in civil engineering - Part 1: Properties of minestone.” *Waste Manag.,* 15(1), 3–42.

Skarzyńska, K. M. (1995). “Reuse of coal mining wastes in civil engineering - Part 2: Utilization of minestone.” *Waste Manag.,* 15(2), 83–126.

Sun, J.S., Dou, Y.M., Chen, Z.X. and Yang, C.F. (2011), “Experimental study on the performances of cement stabilized iron ore tailing gravel in highway application”, *J. Appl.Mech.Mater.,* 97-98, 425-428.

Sunil, B. M., Manjunatha, L. S., Ravi, L., and Yaragal, S. C. (2015). “Potential use of mine tailings and fly ash in concrete.” *J. Adv. Concrete Constr.,* 1, 55–69.

Thiery, M., Dangla, P., Villain, G., and Platret, G. (2005). “A prediction model for concrete carbonation based on coupled CO 2 -H 2 O-ions transfers and chemical reactions.” 10DBMC Int. Conference Durab. *Build. Mater. Components* , 17–20.

Wang, C. L., Ni, W., Zhang, S. Q., Wang, S., Gai, G. S., and Wang, W. K. (2016). “Preparation and properties of autoclaved aerated concrete using coal gangue and iron ore tailings.” *Constr. Build. Mater.,* 104, 109–115.

Wang, J.Z. and Wu, C. (2000), “Effect of energy saving and formation of Portland cement clinker using iron-tailings as raw materials”, *J. Shenyang Arch. Civil Eng. Inst.,* 16(2), 112-114.

Yang, C., Cui, C., Qin, J., and Cui, X. (2014). “Characteristics of the fired bricks with low-silicon iron tailings.” *Constr. Build. Mater.,* 70, 36–42.

Yellishetty, M., Karpe, V., Reddy, E. H., Subhash, K. N., and Ranjith, P. G. (2008). “Reuse of iron ore mineral wastes in civil engineering constructions: A case study.” *Resour. Conserv. Recycl.,* 52(11), 1283–1289.

Zhang, J., Lu, L., Wang, L., and Wang, J. (2011). “Influence of flexural loading on permeability of chloride ion and diffusion coefficients in RC beams.” *Adv. Mater. Res.,* 163–167, 3200–3205.

Zhao, S., Fan, J., and Sun, W. (2014). “Utilization of iron ore tailings as fine aggregate in ultra-high performance concrete.” *Constr. Build. Mater.,* 50, 540–548.

Zheng, Y.C., Ni, W., Xu, L., Li, D.Z. and Yang, J.H. (2010), "Mechano-chemical activation of iron ore tailings and preparation of high-strength construction materials", *J. Univ.Sci.Technol.Beijing*, 32(4), 504-507.

Zhu, L.P., Ni, W., Huang, D., Hui, M. and Gao, S.J. (2011), "Whole-tailings backfilling materials with fly ash", *J. Univ.Sci.Technol.Beijing*, 33(10), 190-1196.

CPAM. (2012): http://www.concreteisbetter.com/vs.html, Concrete Paving Association of Minnesota, last accessed Sept 2019.

(https://en.wikipedia.org/wiki/Perlite). Last accessed Oct 2019.

(https://www.cia.gov/library/publications/resources/the-world-factbook/geos/in.html).

APPENDIX

APPENDIX-I

Table I.1 : Data used for model development for density of IOT-alccofine concrete

w/c	CD	MP	Experimental Density	Predicted Density	Error %
0.35	3	40	2573.00	2622.86	-1.93
	3	50	2566.33	2647.61	-3.16
	7	40	2584.67	2627.34	-1.65
	7	50	2612.00	2652.09	-1.53
	28	40	2656.00	2650.86	0.19
	28	50	2563.67	2675.61	-4.36
	56	40	2665.67	2682.22	-0.62
	56	50	2592.00	2706.97	-4.43
0.4	3	40	2522.67	2565.64	-1.70
	3	50	2514.33	2578.04	-2.53
	7	40	2573.00	2570.12	0.11
	7	50	2558.00	2582.52	-0.95
	28	40	2574.67	2593.64	-0.73
	28	50	2543.33	2606.04	-2.46
	56	40	2688.33	2625.00	2.35
	56	50	2644.00	2637.40	0.25
0.45	3	40	2501.67	2508.43	-0.27
	3	50	2510.67	2508.48	0.08
	7	40	2513.67	2512.91	0.03
	7	50	2505.00	2512.96	-0.31
	28	50	2517.33	2536.48	-0.76
	56	50	2536.00	2567.84	-1.25

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.2 Data used for model validation for density of IOT-alccofine concrete

w/c	CD	MP	Experimental Density	Predicted Density	Error %
0.35	3	40	2573.00	2622.86	-1.94
	3	50	2566.33	2647.61	-3.17
	7	40	2584.67	2627.34	-1.65
	7	50	2612.00	2652.09	-1.53
	28	40	2656.00	2650.86	0.19
	28	50	2563.67	2675.61	-4.37
	56	40	2665.67	2682.22	-0.62
	56	50	2592.00	2706.97	-4.44
0.4	3	40	2522.67	2565.64	-1.70
	3	50	2514.33	2578.04	-2.53
	7	40	2573.00	2570.12	0.11
	7	50	2558.00	2582.52	-0.96
	28	40	2574.67	2593.64	-0.74
	28	50	2543.33	2606.04	-2.47
	56	40	2688.33	2625.00	2.36
	56	50	2644.00	2637.40	0.25
0.45	3	40	2501.67	2508.43	-0.27
	3	50	2510.67	2508.48	0.09
	7	40	2513.67	2512.91	0.03
	7	50	2505.00	2512.96	-0.32
	28	50	2517.33	2536.48	-0.76
	56	50	2536.00	2567.84	-1.26

Notation: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.3 Data used for model development for compressive strength of IOT-alccofine concrete

w/c	CD	MP	Observed compressive strength	Predicted compressive strength	% Error
0.35	3	20	34.33	37.69	-9.80
	3	30	35.67	39.03	-9.42
	3	40	38.00	38.58	-1.52
	3	50	34.67	36.33	-4.79
	7	20	45.00	42.59	5.36
	7	30	47.00	43.93	6.54
	7	40	47.67	43.47	8.80
	7	50	44.00	41.23	6.30
	28	20	61.67	61.43	0.38
	28	30	62.00	62.77	-1.24
	28	40	63.00	62.32	1.08
	28	50	57.67	60.07	-4.16
	56	20	69.33	68.68	0.94
	56	30	69.67	70.02	-0.49
	56	40	70.00	69.56	0.62
	56	50	65.33	67.32	-3.03
0.4	3	20	33.33	36.31	-8.95
	3	30	35.00	36.70	-4.85
	3	40	32.00	35.29	-10.28
	3	50	30.67	32.09	-4.63
	7	20	42.33	41.21	2.65
	7	30	43.67	41.59	4.76
	7	40	42.67	40.18	5.82
	7	50	40.00	36.98	7.54
	28	20	59.00	60.05	-1.77
	28	30	61.33	60.43	1.46
	28	40	58.67	59.03	-0.60
	28	50	55.33	55.83	-0.89
	56	20	67.67	67.30	0.55

w/c	CD	MP	Observed compressive strength	Predicted compressive strength	% Error
	56	30	68.67	67.68	1.44
	56	40	67.00	66.27	1.08
	56	50	62.67	63.07	-0.64
0.45	3	20	32.00	32.49	-1.54
	3	30	30.33	31.92	-5.25
	3	40	29.33	29.56	-0.78
	3	50	26.00	25.41	2.27
	7	20	39.33	37.39	4.94
	7	30	37.33	36.82	1.37
	7	40	34.67	34.45	0.62
	7	50	32.33	30.30	6.27
	28	20	56.67	56.23	0.77
	28	30	54.00	55.66	-3.07
	28	40	51.00	53.30	-4.50
	28	50	48.67	49.14	-0.97
	56	20	65.00	63.48	2.34
	56	30	62.33	62.91	-0.92
	56	40	61.00	60.54	0.74
	56	50	56.00	56.39	-0.69

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.4. Data used for model validation for compressive strength of IOT-alccofine concrete

w/c	CD	MP	Observed compressive strength	Predicted compressive strength	% Error
0.35	3	0	32.00	29.46	7.92
	3	10	31.00	34.39	-10.92
	7	0	47.33	34.36	17.41
	7	10	45.00	39.28	12.71
	28	0	60.33	53.20	11.82
	28	10	59.00	58.12	1.48
	56	0	68.00	60.45	11.11
	56	10	67.33	65.37	2.91
0.4	3	0	30.67	29.96	2.30
	3	10	30.00	33.93	-13.10
	7	0	41.33	34.86	15.66
	7	10	41.67	38.82	6.83
	28	0	57.33	53.70	6.33
	28	10	57.67	57.67	0.01
	56	0	65.00	60.95	6.23
	56	10	65.33	64.91	0.63
0.45	3	0	28.67	28.02	2.25
	3	10	29.33	31.04	-5.81
	7	0	40.00	32.92	17.71
	7	10	40.33	35.93	10.91
	28	0	52.67	51.76	1.73
	28	10	55.33	54.77	1.00
	56	0	57.33	59.01	-2.92
	56	10	60.67	62.02	-2.22

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.5 Data used for model development for splitting tensile strength of IOT-alccofine concrete

w/c	**CD**	**MP**	**Experimental splitting tensile strength**	**Predicted splitting tensile strength**	**% Error**
0.35	28	0	4.21	4.13	1.97
	28	10	4.23	4.25	-0.36
	28	20	4.34	4.36	-0.55
	28	30	4.58	4.48	2.12
	56	0	4.25	4.31	-1.52
	56	10	4.27	4.43	-3.81
	56	20	4.59	4.55	0.83
	56	30	4.77	4.67	2.09
0.4	28	0	3.96	4.00	-0.92
	28	10	4.12	4.11	0.12
	28	20	4.25	4.23	0.39
	28	30	4.53	4.35	3.93
	28	40	4.10	4.47	-9.03
	56	0	4.16	4.18	-0.57
	56	10	4.15	4.30	-3.67
	56	20	4.48	4.42	1.31
	56	30	4.76	4.54	4.63
0.45	28	0	3.84	3.87	-0.67
	28	10	4.06	3.98	1.86
	28	20	4.20	4.10	2.31
	28	30	4.14	4.22	-1.96
	56	0	4.12	4.05	1.61
	56	10	4.11	4.17	-1.50
	56	20	4.36	4.29	1.59
	56	30	4.32	4.41	-2.05

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.6 Data used for model validation for flexural strength of IOT-alccofine concrete

w/c	CD	MP	Experimental	Predicted	Error (%)
0.35	28	0	6.27	6.07	0.031
	28	10	6.20	6.19	0.001
	28	20	6.33	6.31	0.003
	28	30	6.53	6.43	0.016
	56	0	6.40	6.42	-0.003
	56	10	6.27	6.54	-0.044
	56	20	6.60	6.66	-0.009
	56	30	6.93	6.78	0.022
0.4	28	0	5.73	5.78	-0.008
	28	10	5.60	5.90	-0.053
	28	20	6.00	6.02	-0.003
	28	30	6.47	6.14	0.051
	28	40	5.80	6.26	-0.079
	56	0	6.07	6.13	-0.010
	56	10	6.13	6.25	-0.018
	56	20	6.53	6.37	0.026
	56	30	6.73	6.49	0.037
0.45	28	0	5.60	5.48	0.021
	28	10	5.53	5.60	-0.012
	28	20	5.87	5.72	0.025
	28	30	5.80	5.84	-0.007
	56	0	5.87	5.83	0.006
	56	10	5.93	5.95	-0.003
	56	20	6.20	6.07	0.021
	56	30	6.00	6.19	-0.032

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

Table I.7 Data used for model validation for flexural strength of IOT-alccofine concrete

w/c	CD	MP	Experimental	Predicted	% error
0.35	28	40	6.80	6.55	3.66
	28	50	6.13	6.67	-8.77
	56	40	7.20	6.90	4.16
	56	50	6.33	7.02	-10.85
0.4	28	50	5.67	6.38	-12.51
	56	40	6.20	6.60	-6.53
	56	50	5.93	6.72	-13.33
0.45	28	40	5.47	5.96	-9.02
	28	50	5.47	6.08	-11.21
	56	40	5.80	6.31	-8.77
	56	50	5.67	6.43	-13.45

Note: Water-Cement Ratio (w/c); Curing Days (CD); Mix Percentage (MP)

LIST OF PUBLICATIONS

LIST OF PUBLICATIONS BASED ON PH.D. RESEARCH WORK

1. **B. C. Gayana** and K Ram Chandar (2018). 'Sustainable use of mine waste and tailings with suitable admixture as aggregates in concrete pavements-A review'. *International Journal of Advances in Concrete Construction*. 6(3). pp. 221-243. ***(SCIE, Scopus)***

2. **Gayana B C** and K Ram Chandar (2018). "A study on suitability of iron ore overburden waste rock for partial replacement of coarse aggregates in concrete pavements". *IOP Conference Series: Materials Science and Engineering.* Vol. 431(6)-102012. ***(Scopus)***

3. **Gayana B C**, Shashanka M, Avinash Rao and Ram Chandar K (2019). "An experiment investigation on physical and mechanical properties of high strength concrete with suitable admixture". *Materials Research Forum*. Vol. 972. Pp. 10-15 ***(Scopus)***

4. **Gayana B C**, Prince, and Ram Chandar K (2019). "Geopolymer bricks using mine waste and additives as a construction material". *The Indian Mining & Engineering Journal.* 58(9). pp. 38-40

5. **Gayana B C** and Ram Chandar K (2019). "Experimental and statistical evaluation of strength properties of concrete with iron ore tailings as fine-aggregate". *Journal of Hazardous, Toxic, and Radioactive Waste. ASCE.* 24(1), 04019038. DOI: 10.1061/(ASCE)HZ.2153-5515.0000480 ***(Scopus)***

BIO-DATA

BIODATA

1. Name	:	Gayana B C
2. Father's Name	:	Chinnappa M
3. Date of Birth	:	06-02-1989
4. Nationality	:	Indian
5. Marital Status	:	Married
6. Present Position	:	Research Scholar
7. Address for Communication	:	# 313, Y cross, 3 rd. block, HRBR layout, Kammanahalli, Kalayanagar, Bangalore, Karnataka India.
8. Mobile	:	+91-9483368185
9. E-mail	:	bcgayana@gmail.com

10. Academic Qualifications:

Degree	**University/ Board**	**Year of awarding degree**
M.Tech (Transportation Engineering & Management)	BMSCE, Bangalore	2012
B. E (Civil Engineering)	MSRIT, Bangalore	2010

PUBLICATIONS

- **Gayana B C** and Ram Chandar K (2020). "Evaluation of strength properties of concrete with iron ore tailings as fine- aggregate using experimental and statistical studies". Journal of Hazardous, Toxic, and Radioactive Waste. ASCE. 24(1), 04019038. (Scopus)

- **Gayana B C**, Ram Chandar K and Krishna R Reddy (2020). "Influence of laterite and sandstone on the mechanical properties of concrete". Sustainable Environmental and Infrastructure, Part of Lecture notes in civil engineering-Springer. 90, pp. 117-128. (Scopus)

- Sharath S, **Gayana B C** and Krishna R Reddy, Ram Chandar K, (2019). "Experimental investigations on performance of concrete incorporating precious slag balls (PS balls) as fine aggregates". International Journal of Advances in Concrete Construction. 8(3), pp. 239-246. (SCIE)

- **Gayana B C**, Shashanka M, Avinash N Rao and Ram Chandar K (2019). "An experimental investigation on physical and mechanical properties of high strength concrete with suitable admixture". Materials Research Forum. 972. pp 10-15. (Scopus)

- **Gayana B C,** Shashanka M, Avinash N Rao and Ram Chandar K (2019). "Physico-mechanical properties of concrete with industrial Waste - A case study". Proceedings of the 4th World Congress on Civil, Structural, and Environmental Engineering (CSEE'19). DOI: 10.11159/icsect19.145.

- **Gayana B C** and Ram Chandar K (2018). "A study on suitability of iron ore overburden waste rock for partial replacement of coarse aggregates in concrete pavements". IOP Conference Series: Materials Science and Engineering. 431(6)-102012. (Scopus)

- Shubhananda Rao P, **Gayana B C** and Ram Chandar K (2018). "Use of iron ore tailings in infrastructure projects". International Journal of Mining and Mineral Engineering. 10(1). pp. 51-67 (Scopus)

- **Gayana B C** and Ram Chandar K (2018). "Sustainable use of mine waste and tailings with suitable admixture as aggregates in concrete pavements-A review". International Journal of Advances in Concrete Construction. 6(3). pp. 221-243. (SCIE)

- Ram Chandar K, **Gayana B C** and Sainath V (2016). "Experimental investigation for partial replacement of fine aggregates in concrete with sandstone". International Journal of Advances in Concrete Construction. 4(4). pp. 243-261. (SCIE)

INTERNATIONAL CONFERENCES

- **Gayana B C** (2015), Participated in the 3rd Conference of Transportation Research Group (CTRG) of India. The Lalit Great Eastern, Kolkata, December 17-20.

- **Gayana B C,** Sharath S and K Ram Chandar (2017). "Mechanical and durable properties of concrete with precious slag balls (PS Balls) as replacement for fine aggregates". 6th International Engineering Symposium (IES-2017). Kumamoto University, Japan, March 1-3.

- **Gayana B C** and K Ram Chandar (2018). "A study on suitability of iron ore overburden waste rock for partial replacement of coarse aggregates in concrete pavements". 14th International Conference on Concrete Engineering and Technology (CONCET 2018). Kuala Lumpur, Malaysia, August 7-10.

- **Gayana B C** and Avinash Rao (2018). "Effect of steel slag and quarry dust on the flexural strength of concrete". 3rd International Conference on Recent Advances in Engineering Sciences. M S Ramaiah Institute of Technology, Bengaluru, September 26-27.

- **Gayana B C**, Shashanka M, Avinash Rao and Ram Chandar K (2019). "An experimental investigation on physical and mechanical properties of high strength concrete with suitable admixture". ICBMC-2019: 4th International Conference on

Building Materials and Construction, National University of Singapore, February 25-28. (Best Presentation)

- **Gayana B C** (2018), Participated in International conference on Sustainable Construction and Building Materials. National Institute of Technology Karnataka, Surathkal. June 18-22.

- **Gayana B C**, Shashanka M and Ram Chandar K (2019). "Physico-Mechanical Properties of Concrete with Industrial Waste - A Case Study". ICSECT-2019: 4th International Conference on Structural Engineering and Concrete Technology, Italy, Rome. April 7-9.

- **Gayana B C**, Prince and Ram Chandar K (2019). "Geopolymer brick using mine waste and additives as a construction material". National Seminar on Mining and Processing of Raw Materials for Steel-Cement and Power, Hotel Mallige, Hospet, September 21-22.

- Shubhanand Rao, **Gayana B C** and Ram Chandar K (2020). "Experimental study on iron ore tailings as aggregate in development of bricks and concrete". International Conference on Advances in Material Science 2020, Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar, India, October 3.

WORKSHOPS

- Workshop on "Pavement Design, Evaluation and Material Characterization (PAVE)"organized by Transportation Engineering Section, Civil Engineering Department, Indian Institute of Technology Kharagpur during December 21-23, 2015.

- Two day National Seminar in Concrete Panorama and Deminar by Indian Concrete Institute, Bangalore Centre during February 25-26, 2016 at NIMHANS Convention Centre, Bangalore.

- GIAN course on "Engineering Analysis and Design of Rigid Pavements" during July 25-29, 2016 at National Institute of Technology Karnataka, Surathkal.

- Workshop on “Design and Development of Sustainable Concrete in the Era of Global Warming” organized by the Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal, during January 9-10, 2017.
- Workshop on “Recent Trends in Environment, Health and Safety Management in Mining and other Core Industries” organized by the Department of Mining Engineering, National Institute of Technology Karnataka, Surathkal, during January 27-28, 2017
- National-Level Faculty Development Programme on “Data Analytics using R” during July 24-25, 2017 at Reva University, Bangalore.
- GIAN short term course on “Computer Application and Data Analysis in Mining and other Core Industries” organized by the Department of Mining Engineering, National Institute of Technology Karnataka, Surathkal, during March 12-16, 2018.
- GIAN course on “Concrete: Microstructure Characterization” organized by the Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal, during June 18-22, 2018
- Two Weeks GIAN Course on “Sustainable Roadways- Design, Construction and Maintenance” held at Sri Jayachamarajendra College of Engineering, Mysuru during July 23- August 3, 2018.
- Workshop on Recent Advances in Reliability Engineering and Maintenance Management (RAREMM-2018) sponsored by TEQIP-III and organized by Department of Mining Engineering at National Institute of Technology Karnataka, Surathkal during November 1-3, 2018
- Workshop on “Concepts of Operations Analysis and Geo-Mechanics for Improved Production and Safety (COAGIPS-2019) organized by Department of Mining Engineering at National Institute of Technology Karnataka, Surathkal during February 11-13, 2019.

PROFESSIONAL DEVELOPMENT HOURS (PDHs) AND CONTINUATION EDUCATION UNITS (CEUs) CERTIFICATES

- The Concrete Convention and Exposition in Rosemont, IL (Virtual Sessions): Open Topic Session, Part 1 of 2, American Concrete Institute awards 0.2 Continuing Education Units (CEUs) for 2 Professional Development Hours (PDHs). June 1, 2020.
- The Concrete Convention and Exposition in Rosemont, IL (Virtual Sessions): Textile Reinforced Cement Composites- New Applications and Repair Materials, American Concrete Institute awards 0.3 Continuing Education Units (CEUs) for 3 Professional Development Hours (PDHs), June 1, 2020.
- The Concrete Convention and Exposition in Rosemont, IL (Virtual Sessions): Design, Construction, and Performance of Continuously Reinforced Concrete Pavements, American Concrete Institute awards 0.2 Continuing Education Units (CEUs) for 2 Professional Development Hours (PDHs), June 2, 2020.
- The Concrete Convention and Exposition in Rosemont, IL (Virtual Sessions): Bond and Development in New Types of Concrete and Reinforcement, Part 1 of 2, American Concrete Institute awards 0.2 Continuing Education Units (CEUs) for 2 Professional Development Hours (PDHs). June 3, 2020.
- The Concrete Convention and Exposition in Rosemont, IL (Virtual Sessions): Rethinking Reinforcement for 3-D Printed Cementitious Composites, American Concrete Institute awards 0.2 Continuing Education Units (CEUs) for 2 Professional Development Hours (PDHs). June 3, 2020.
- National Concrete Pavement Technology Centre; Concrete Pavement Joint Design, Layout and Construction, 1 Professional Development Hours (PDHs). August 18, 2020.
- National Concrete Pavement Technology Centre; Resiliency/Resilient Pavement Systems Webinar, 1 Professional Development Hours (PDHs). September 22, 2020.

PROFESSIONAL MEMBERSHIP

- International Society for Concrete Pavements (ISCP). Student Member, August 22, 2016 to December 10, 2020.
- American Society of Testing and Materials (ASTM), Student Member No. 2163018, 2019.
- American Society of Civil Engineers (ASCE), Student Member No. 000011619568, December 31, 2020.
- American Concrete Institute (ACI), Student Member No. 1446327, August 14, 2019 to August 31, 2021.