EFFECT OF PARTIAL REPLACEMENT OF FINE AGGREGATES BY CUPOLA FURNACE SLAG ON PROPERTIES OF CONCRETE

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by:

NAMRATA THAKUR

801624017

Under Supervision of

Dr. MANEEK KUMAR
Professor, CED

Dr. JASWINDER SINGH SAINI
Associate Professor, MED

CIVIL ENGINEERING DEPARTMENT

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY

(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB JUNE, 2018

DECLARATION

I, Namrata Thakur hereby declare that the work presented in this thesis entitled **"EFFECT OF PARTIAL REPLACEMENT OF FINE AGGREGATES BY CUPOLA FURNACE SLAG ON PROPERTIES OF CONCRETE"** in fulfilments of the requirement for the award of degree of **Master of Engineering** in **Structural Engineering** submitted at Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of **Dr. Maneek Kumar, Professor,** Department of Civil Engineering and **Dr. Jaswinder Singh Saini, Associate Professor,** Department of Mechanical Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala from January to July, 2018.

The matter presented herein has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date:

(NAMRATA THAKUR)
Roll No.: 801624017

(Dr. Maneek Kumar)
Professor and Dean of Student Affairs
Department of Civil Engineering
Thapar Institute of Engineering & Technology
(A Deemed To Be University), Patiala, Punjab

(Dr. Jaswinder Singh Saini)
Associate Professor
Department of Mechanical Engineering
Thapar Institute of Engineering & Technology
(A Deemed To Be University), Patiala, Punjab

ACKNOWLEDGEMENT

Time has provided me the cherished opportunity to express my heartfelt gratitude to my guides Dr. Maneek Kumar, Professor, CED and Dr. Jaswinder Singh Saini, Associate Professor, MED, Thapar University, Patiala, who permitted me to carry out research work under their able guidance. I shall ever remain indebted to them for their meticulous guidance, constructive criticism, clear thinking, keen interest, constant encouragement and forbearance right from the beginning of this research to its completion.

I wish to express my sincere thanks to Dr. Prem Pal Bansal, Associate Professor and Head, CED, Thapar University, Patiala, who has been a constant source of inspiration for me throughout this thesis work. The cheerful support of my friends and colleagues is sincerely appreciated. Special words of appreciation go to Sh. Ram Sumiran, Sh. Varinder Kumar Sharma and other laboratory colleagues who helped me in my experimental work. I am also thankful to all the staff members of Civil Engineering Department for their full cooperation and help.

Above all, I thank my parents, whose love and affectionate, blessing have been a constant source of inspiration in making this manuscript a reality. I render my gratitude to the almighty who bestowed self-confidence, ability and strength in me to complete this work. I also acknowledge the financial support provided by DST and PSCST for smooth completion of my work.

(NAMRATA THAKUR)

ABSTRACT

In the present scenario, the emphasis is on the avoidance of waste generation, recycling and reuse of waste, and minimizing the adverse impact of waste disposal on the environment. With increasing capacities, disposal of large quantities of slag becomes a big environmental concern and a critical issue for foundry industries. The good quality aggregates is also depleting day by day due to tremendous growth in construction industry. Aggregates are the main ingredient of concrete occupying approximately 75% of its volume and directly affecting its fresh as well as hardened properties.

The objective of the present work is to utilize the Cupola furnace slag as partial replacement to fine aggregates in the concrete mix and to study the effect on mechanical and durability properties of concrete. The chemical composition of cupola furnace slag varies widely depending upon the coke quality, contamination of charging material and quantity as well as quality of lime stone used in cupola furnace. The chemical composition of cupola furnace slag is analyzed from three different foundry clusters of Punjab before partially replacing it as fine aggregate. The results show that the compressive strength as well as the split tensile strength of the concrete is increased by partial replacement of fine aggregate up to 30% replacement level with cupola furnace slag whereas a continuous increasing trend is observed in case of durability properties. The percentage increase in the strength values is higher for lower water-cement ratios indicating its suitability for use in concrete mixes. Highest increase in strength values, both compressive as well as split tensile, is achieved for a 30% replacement of fine aggregates with cupola furnace slag, indicating that 30% cupola slag is the optimum replacement percentage of fine aggregates in the concrete mixtures. The compressive and tensile strength of the concrete decreases beyond 30% replacement of fine aggregate with cupola slag whereas same is not observed in case of durability properties.

CONTENTS Page No.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Iron ore are rocks and minerals from which metallic iron can be economically extracted. The ores are generally rich in various oxides of iron and vary in color from dark grey, bright yellow, deep purple to rusty red. Iron itself is usually found in the form of magnetite (Fe_3O_4, 72.4% Fe), hematite (Fe_2O_3, 69.9% Fe), goethite (FeO (OH), 62.9% Fe), limonite (FeO (OH) ·n (H_2O), 55% Fe) or siderite ($FeCO_3$, 48.2% Fe). Iron ore is being used from the times of prehistory to the early middle Ages where knowledge of production processes is derived from archaeological investigation. Moreover, Slag is produced as a by-product of iron-working processes such as smelting etc. and after that it was left at site as a waste product rather than being moved away. Now-a-days different types of slags are formed as a by-product of iron and steel industry, thus tonnes and tonnes of slag is getting accumulated day by day.

Considering one of the slags which is readily available nowadays as a waste product from different furnaces is Cupola Slag. Its name is derived from the furnace it is extracted from as a by-product. Cupola furnaces were built in China during Warring States period starting from (403 to 221 BC). During the Han Dynasty (202 BC – 220 AD), most, if not all, iron smelted in the furnace was remelted in a cupola furnace. It was designed so that a cold blast injected at the bottom traveled through tuyere pipes across the top where the charge (i.e. of charcoal and scrap or pig iron) was dumped, further the air becomes a hot blast before reaching the bottom of the furnace where iron was melted and then drained into appropriate moulds for casting.

Further research was going on and a modern cupola furnace was made by French scientist and entomologist **René-Antoine Ferchault de Réaumur** around 1720 and the first cupola patent was taken out in England in the late eighteenth century. There are almost 6000 Cupola furnaces installed in India, out of which approximately 1000 Cupola furnaces are installed in Punjab alone and thus produce tonnes and tonnes of slag as a waste product. Moreover, as natural aggregates are being mined for years from quarries, thus they are gradually depleting as natural resources are not infinite. Replacing natural aggregate by recyclable and industrial waste materials, offers the important benefit for the environment in minimizing excess of landfill. Another important benefit is that further energy required for refining or extraction purpose will be reduced , which significantly reduces the release of CO_2 into atmosphere and thus causing less harm to environment.

This chapter contains brief introduction of cupola furnace, working of the furnace, slag structure etc. It even gives us insight about the production of cupola slag whose name is derived from the furnace it is being obtained from. Moreover, it gives us detail about its applications and problems which arise due to slag production.

1.2 CUPOLA FURNACE

A **cupola** or **cupola furnace** is a melting device usually used in foundries for the purpose of melting of cast iron, bronze etc. These furnaces can be made of almost any size. The size of a cupola furnace is usually expressed in diameter and can vary from 1.5 to 13 feet (0.5 to 4.0 m). Cupola furnace is generally cylindrical in shape and the equipment is arranged vertically, usually supported on four legs. The bottom of the cylinder is fitted with doors which swing in downward and outward direction to 'drop bottom'. The top from where gases escape can be open or fitted with a cap to prevent rain from entering the furnace. Further to control emissions, furnace may be fitted with a cap that is designed to pull the gases into a device, to cool gases and then remove the particulate matter present in it.

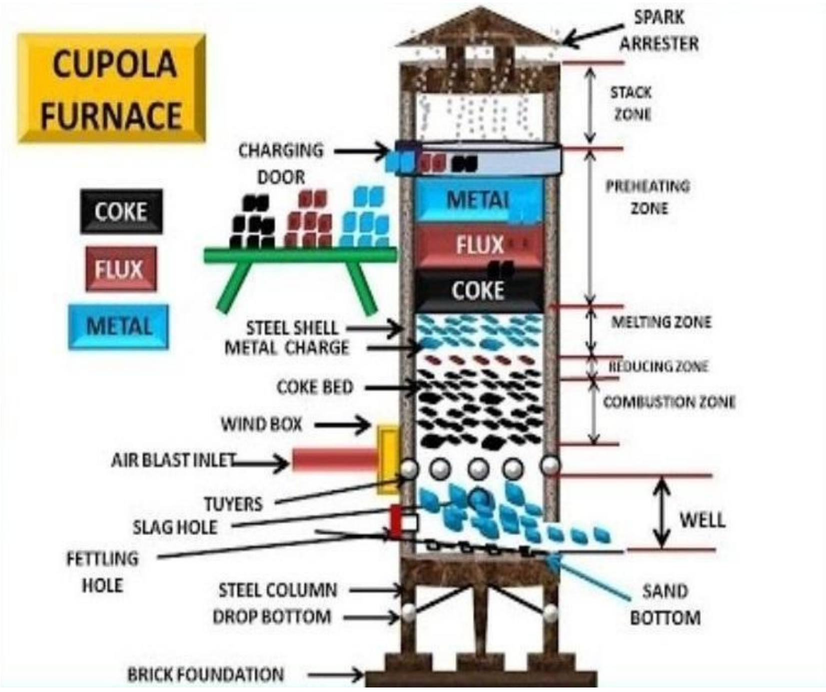


Fig. 1.1 Cupola furnace ***(www. google.com)***

1.3 WORKING OF CUPOLA FURNACE

To begin with the production, furnace is filled with layers of coke and ignited with torches whereas other smaller cupolas may be ignited with wood in order to start burning of coke. When the coke is burned, air is introduced to the coke bed through ports present on sides called tuyeres.

When the coke is at higher temperature, then solid pieces of metal are put inside the furnace through an opening present at the top. Then the metal is alternated with additional layers of fresh coke just to enhance burning process. Further limestone is added which will act as a1flux. As the heat rises within the stack of metals and coke, the metal starts melting. It drips down the coke bed to further get collected in a pool present at the bottom, just above the bottom doors. During the melting process occurring, a thermodynamic reaction is observed between the fuel and the blast air sent through tuyeres. The carbon present in the coke combines with the oxygen in the air to form a compound named as carbon monoxide. The carbon monoxide further reduces to form carbon dioxide. Part of the carbon is picked up by the droplets of metal which is in molten state, which enhances the carbon content of the iron. Silicon carbide and ferromanganese blocks may also be added to the charge materials. Silicon carbide breaks down and the carbon and silicon present in it enters into the molten metal. Similarly, the ferromanganese melts and gets combined into the liquid iron in the 'well' present at the bottom of the cupola furnace. Additions to the molten iron such as ferromanganese, Silicon carbide and other alloying agents are used in order to alter the molten iron to match up to the standards of the castings at hand.

The one operating the cupola is known as the "cupola tender" or in other words as "furnace master". During the operation of a stored cupola (as cupolas may vary in this regard) the master observes the amount of iron rising in the well of the furnace. When the metal reaches to sufficiently high level, the furnace master opens the "tap hole" to let the metal flow out, into a ladle or any other container in order to hold the molten metal. When required amount of metal is collected from the "tap hole" it is plugged with a refractory plug which is made of clay.

The furnace master observes the furnace through the sight glass or peep sight in the tuyeres. Cupola slag will rise to the top of the pool of iron being formed. A slag hole, which located at the higher side on the cylinder of the furnace, and usually is located to the rear or side of the tap hole, is usually opened to let the slag flow out. As the viscosity is low (even with proper fluxing) thus the red hot molten slag will flow easily. At a times the slag which runs out the slag hole is collected in a small cup shaped tool, then allowed to cool and harden. It is further fractured and visually examined. With acid refractory lined cupolas a greenish colored slag signifies that the fluxing is proper and adequate whereas, in basic refractory lined cupolas the slag is brown.

After the furnace has produced required amount of metal to supply the foundry with its needs, the bottom is opened and the remaining material is allowed to fall on the floor between the legs. This material is allowed to cool and thereafter removed. Same furnace can be used again and again. A 'campaign' may last a few hours, a day, weeks or even few months.

When the operation is over, the blast is shut down and the prop under the bottom door is knocked down so that the bottom plates will swing open. This enables the furnace remains to drop to the floor or in a bucket. They are further then quenched and removed from underneath the furnace.

1.4 SLAG GENERATION

In the cupola furnace, for production of near about 1Tonne of molten metal, approximately 50 kg of slag is produced *i.e.* 5% of the molten metal is produced. In the picture present below slag formation is shown i.e. Fig. 1.2. On a general basis, the furnace operates for the duration of 7-8 hrs/heat producing 20-25T of molten metal/heat depending on the size of furnace (which may vary). The amount of slag generated is around 1000 - 1200 kg/ heat. It can be calculated that for 1000 cupola units, the quantity of slag generated is 1000-1200 T/heat. The amount of slag generated is very large as compared to its negligible productive utilization in any of the manufacturing process. It is merely used for the purpose of land filling that too with the increase on financial burden on the industrialists for the slag clearance.

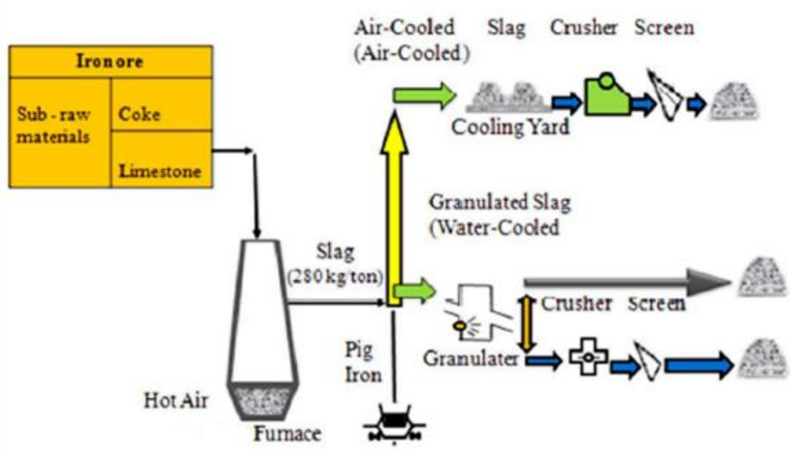


Fig. 1.2 Process of formation of slag *(www.google.com)*

1.5 CUPOLA SLAG STRUCTURE

It is dense, solid and vitrified material that usually varies in color from grey to dark brown after calcination of the slag at 700^0C for near about 5 hours, but the colors which generally dominate are grey to brown. Basicity of the slag is most important feature, thus in case of cupola slag its basicity is in the range of acid to basic slag. Moreover, if the slag turns out to be light in color it is associated with high basicity materials whereas the one with the darker slag is associated with more oxidizing conditions which were present in the furnace. If in case the iron content is too high and the lime level is too low, then the slag converts to aero chocolate appearance instead of being solid. On counterpart some slag will exhibit light colored grains in their structure which are usually refractory particles eroded from the furnace lining and now can be seen in the slag. The physical condition of the slag is even influenced by the way it is collected. Conventional cold blast cupolas are usually operated such that whatever amount of slag produced is tapped from the furnace directly into slag bogeys present there or into pits present in the floor of the foundry. In either of the cases the slag solidifies in relatively large pieces, subsequently it may break down into various size pieces or fragments. Some large furnaces operate with a wet slag granulation system as well where the slag coming out of the furnace tapping box is broken up by a water stream. The slag collected or extracted from such kind of operation is comparably fine as compared to the slag fragments obtained from conventional practice. Moreover, it derived its name from the furnace it is extracted.

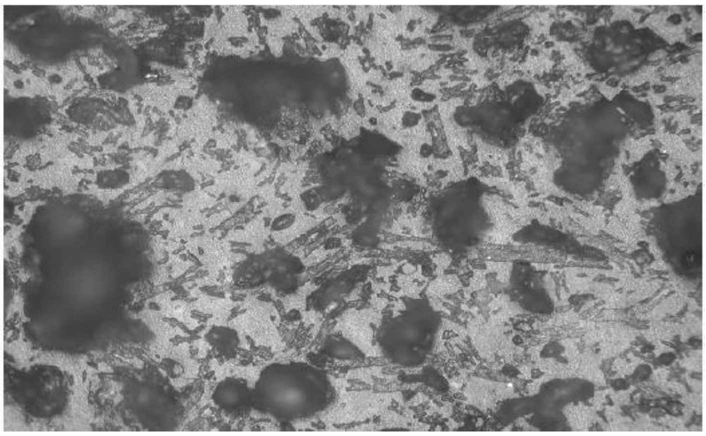


Fig.1.3 Slag structure *(www.google.com)*

1.6 PROPERTIES OF SLAG

Physical properties of the cupola slag and its chemical composition during working of the furnace are shown below in Table 1.1

Table 1.1 Physical Properties and Chemical Composition of slag *(Behera et al., 2011)*

S. No.	Parameters	Value
Physical properties		
1.	Specific Gravity	3.5
2.	Impact Value	6.1 %
3.	Crushing Strength	35.5 MPa
4.	Water Absorption	0.4 %
Chemical properties		
1.	SiO_2	48.7%
2.	Al_2O_3	11.8%
3.	Fe_2O_3	11.1%
4.	CaO	21.2%
5.	MgO	1.3%
6.	K_2O	1.4%
7.	Remaining are the traces of SO_3, Mn_2O_3, and Sulphide etc.	

1.7 REASONS FOR USAGE OF CUPOLA SLAG

Human beings always find some or the other innovative ideas in order to fulfill their requirement or desire. The scarcity of natural resources such as natural aggregate, usually used in concrete, has compelled many researchers to give a thought about the replacement options, as our nature is not capable to provide enough raw materials to human beings, for their usage and moreover in order to fulfill their desire as well. Now-a-days, generally emphasis is on ways to avoid waste generation and further heed towards recycling and reuse of waste products more and more, thus minimizing the adverse impact of disposal of slag on the environment. With increase in capacity, disposal of large quantities of slag has become a big environmental concern and further converting to a critical issue for foundry industries. Moreover, availability of fine quality aggregates is getting depleted day by day due to tremendous increase in growth of Indian construction industry. Being aggregates, the main ingredient of the concrete structure, thus approximately 75% of its volume is occupied by them and thereafter directly affecting the fresh and hardened properties of concrete. The concrete, being used in majority of the construction work, thus requiring good quality of aggregates in large amount and further affecting resources. Due to such situation arising we felt the need to identify and allocate possible alternative source of aggregate to attain the futuristic growth of aspiring construction industry.

Use of slag as fine aggregates opens us to great opportunity of utilizing the waste product as an alternative to available fine aggregates. Proper usage of waste materials can affect Indian economy and environment in a useful way. With every passing day or within a span of time, waste management is becoming more and more popular because of limited resources and along with this it is one of complex and challenging problem which India is facing currently on environmental front. The waste products generated are usually hazardous to environment directly or indirectly, leading to problems due to rapid increase of industrialization. Therefore, construction industry has always gone through such problems and has even found ways to tackle such kind of problems arising due to generation of waste products. Using of slag, which is also a waste generated by various foundry industries, in concrete as a replacement of fine aggregate not only helps in reducing various green house gases present in the atmosphere but also help in making environment sustainable and moreover slag is a nonmetallic inert waste product which is mainly composed of silicates, alumina silicates, and even calcium-alumina-silicates, thus can be used as a replacement.

1.8 APPLICATIONS OF SLAG

1. Replacement to natural coarse aggregate in concrete mix.
2. Replacement of fine aggregates in concrete mix
3. Road building material in rigid and flexible pavement
4. It can be used in glass manufacturing
5. Roofing granules
6. Production of blended cement.
7. Anti-skid material or tile manufacturing
8. Rail ballast
9. Concrete admixture
10. Earth fill, sub base and base of pavement

All these applications are on general usage of cupola slag either in small quantity or in larger one depending on the requirement basis.

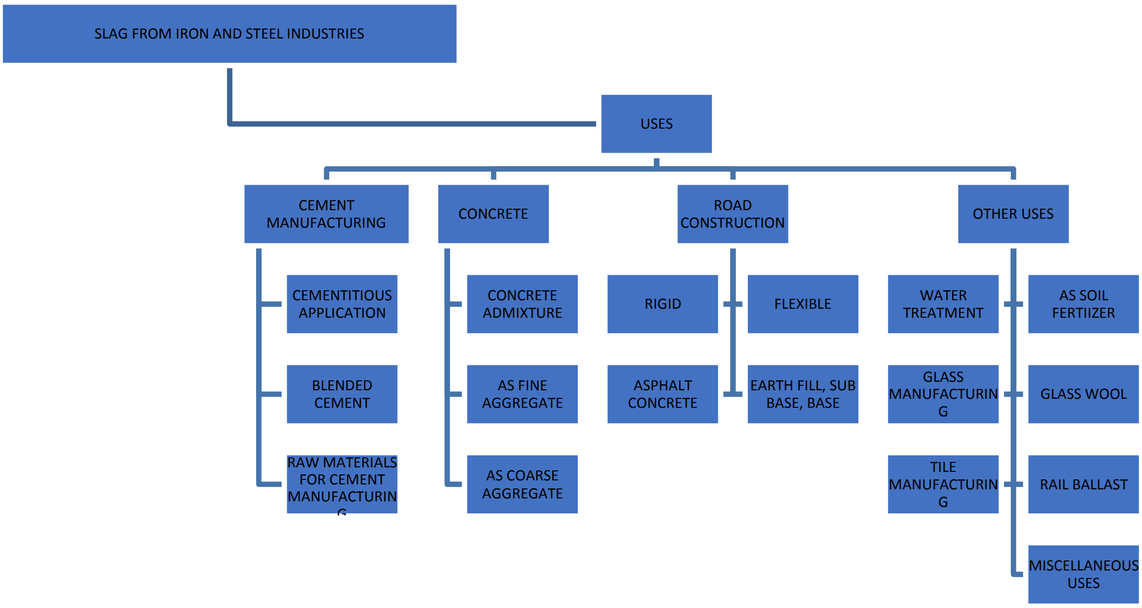


Fig.1.4 Uses of slag *(www.google.com)*

1.9 PROBLEMS ARISING DUE TO SLAG FORMATION

- **Alloy Loss**

When iron oxide slag comes in contact with molten or liquid cast iron, the elements like carbon, silicon and manganese are further oxidized into their respective oxide. Moreover, iron oxide converts expensive alloy materials into oxides which are almost worthless.

$$FeO_{slag} + C_{iron} = CO + Fe \qquad .....(1.1)$$

$$FeO_{slag} + S_{iron} = \frac{1}{2} SiO_{2slag} + Fe \qquad .....(1.2)$$

$$FeO_{slag} + Mn_{iron} = MnO_{slag} + Fe \qquad .....(1.3)$$

Even though, MnO is a product of FeO oxidation, but MnO in turn can oxidize silicon and carbon and can further create many kinds of problems similar to the one in case of iron oxide.

- **Desulphurization**

Desulphurization of molten or liquid iron can be carried out in the furnace or in a container. It is usually known to us that the level of CaO in the slag, usually refers to basicity present in the slag, thus is an important controlling factor. Whereas, the level of MnO present in the slag even plays an equally important role. Higher the MnO level, poorer will be the desulphurization. Thereafter presence of liquid slag entering the cupola with the iron stream or which is produced by oxidation in the furnace can deteriorate the ability of cupola to desulphurize.

- **Refractory Problems**

Usually the inner surface of the cupola furnace is lined or made up with the refractory material which is generally susceptible to erosion because of the formation of slag. The slag can further combine with refractory material which is eroded and can lead to the formation of elements which will affect the production of furnace. Therefore, the consequences arising due to refractory problems leads to production loss and thereafter increasing the cost to replace the eroded refractory.

- **Casting Defects**

The slag entering the mould can even lead to holes or inclusion in the material thus deteriorating its quality. Casting defects of slag which is rich in iron oxide can lead to various reactions which will make the material porous and even lead to the formation of Carbon monoxide. Moreover, slag which is rich in iron oxide can lead to inhibition of nucleation of graphite by further oxidization of the holes present in the material.

1.10 SCOPE OF THE STUDY

The work done in the above study and the way it is presented is basically an effort made in order to study the changes which concrete undergoes on replacement of the fine aggregate by slag. Moreover, emphasis is to study the mechanical and durability properties i.e. in order to study the changes or variation which concrete undergoes by usage of cupola slag as one of its components during casting stage. The slag which is used in this study is collected from the foundry industries which are present in various parts of the Punjab region, and thus being used as partial replacement of fine aggregates in the study which is being carried out. Mechanical and durability properties of the concrete such as compressive strength, split tensile strength, water permeability and abrasion test are the ones which are studied in detail in this study.

CHAPTER - 2
LITERATURE REVIEW

2.1 GENERAL

According to various figures huge number of researchers have shown their interest in the field of utilization of various type of waste products extracted from the industries in the form of slag and thus finding innovative ways out which caters for replacement of few components in concrete. The waste product or slag collected can be used in various concrete mixes, in case of cement production, or as an insulation material, and even as a soil conditioner etc. The way each researcher refers to the utilization of cupola slag in various thrust areas are being discussed in the below section and thus highlighting the importance of each research carried out in this regard.

2.2 UTILIZATION OF CUPOLA SLAG AS AGGREGATE IN CONCRETE

Naik (2002) stated that the waste products can be used efficiently in various concrete mixes. The materials in his studies included are foundry sand and cupola slag which is obtained from different metal-casting industries. Cupola slag is also used as a replacement of coarse aggregate in various concrete mixes. Density (1280 kg/m3) of cupola slag is within the range that of normal weight aggregate (1600 kg/m3) and even structural lightweight aggregate which is (1120 kg/m3). From absorption point of view cupola slag has lower absorption as compared to that for the structural aggregate (lightweight). But in case of air-cooled foundry slag, it was used in concrete as a replacement of about (50% and 100%) for the coarse aggregates, whereas foundry sand was used as a partial replacement (up to 35%) of the fine aggregate used for masonry blocks and paving stones.

Zeghichi (2006) stated that the selection of aggregates is important, as their quality plays a vital role, as their impact is just not limited to controlling the strength of the concrete but do affect its characteristics, and thus in return affecting the durability and performance of concrete mix. When we allow slag to cool slowly, it gets solidified into a grey, crystalline, stony material, which is called as air cooled, or dense slag as shown in **Fig. 2.1.** This lead to the formation of the material used as a concrete aggregate, which in turn is a silico calcareous rock, like that of basalt, which is angular from aspect point of view, rugous and is of micro alveolar structure. When the liquid slag is cooled very rapidly by using various method such as either by pouring into a large excess of water, or generally by subjecting the slag stream to jet of water. Thus, quenching breaks the material into small fragments and thus, solidifies as a glass. This product is called as granulated slag and is further used as cement, or sand for concrete mix. Granulated slag can be used as a replacement to the natural sand in concrete and same can be said about the slag which is in crystallized form thus known as crystallized slag, which after crushing contain excellent normalized aggregates. Zeghichi stated that the compressive strength increases with the passing time or the age of sample. Improvement in strength was observed for the mix with 30% replacement of granulated slag, as compared to that of controlled concrete at all ages was reported. There was significant increase in the strength at an early age (3days) for about 50% replacement with granulated slag mix and further similar trend was observed at all other ages. Moreover, complete substitution of sand by granulated slag lead to decrease in strength at early ages. Thus, slag acts as a real binder, during the hydration process of Portland cement and in turn Ca $(OH)_2$ enters the reaction with other slag components, leading to formation of CSH gel, which plays an important role in filling empty spaces present in the binding medium thus further reinforcing the concrete structure and making it more susceptible.

Fig.2.1 Cupola furnace slag *(Zeghichi (2006))*

Xiong et al. (1992) said that the concrete which is prepared from the pozzolanic slag is activated by the alkali which has best mechanical and durability properties, which helps in turning the slag into a useful resource. During the process of cement production, slag can help in lowering the environmental load in terms of landfill and thus increases the utilization rate of slag due to very low energy consumption without emission of CO_2 in the environment and further using the slag in mixed form. Thereafter during the concrete production, the aggregate which is having higher content of silt and powders present in it can be used with various materials such as sea sand and powdered sand.

Behera et al. (2011) observed the variation of strength in concrete with percentage replacement of slag. On percentage increase in weight for the specimens which were prepared using slags for the various mixes prepared such as for M20, M40, M60, M80, M100 etc. with respect to the natural aggregate was observed to be increasing i.e. increase in compressive strength was found to be like

3.26%, 10.87%, 17.39%, 26.09% and 34.78% respectively. Further he even concluded that, when aggregate is replaced completely by slag in terms of weight then there is increase of just 6.04% whereas compressive strength increases up to 34.78%.

Nadeem et al. (2012) concluded that the compressive strength of concrete has shown an increase of almost 4% to 6% on replacement of both coarse and fine aggregates for percentage replacement of 30% to 50%. Mixing of slag and casting of concrete blocks is usually done in a systematic manner. Moreover, in case of coarse aggregates the compressive strength is generally increased from 5% to 7% and has decreased in case of fine aggregate approximately 7% to 10% upon 100% replacement in case of control mixes i.e. M20, M30 and M40 grade of concrete. On complete replacement of standard crushed coarse aggregate with cupola slag as an aggregate further improved flexure and split tensile strength by almost 6% to 8% in all the concrete mixes. Thus, the basic improvement in strength is caused due to the texture of rough surface which in return ensure strong bonding and further adhesion between the aggregate particles and cement mixture. Coming to the case of fine aggregate replacement with that of cupola slag the strength is increased near about 5% to 6% on 50% replacement but it is reduced by almost 6 to 8% on 100% replacement. The main reason for reduction in strength on complete replacement was merely due to the presence of coarser size particles which could easily be overcome by some addition of finer materials.

From the above conclusions, it can easily be recommended that the cupola slag because of to chemical composition and due to its chemical inertness, soundness of aggregate and concrete, can be efficiently used as aggregates whether in coarse state or fine state used in all constructions like plain and reinforced cement concrete, further including pavement concrete or as partial or full replacements starting from the range of 50 to 100%.

Ramesh et al. (2013) represented that the furnace and welding slag can further be utilized as a building material which acts as additional one to that of concrete. When it comes to welding slag and furnace slag, they give concrete better performance in case of compressive strength. Compressive strength after 7 days increases from about 10% to 15% on replacement by sand with welding slag, whereas compressive strength after 28 days of concrete cubes further increases from 5% to 15% on replacement of sand with welding slag. Moreover, the results portray that 5% of the welding slag and 10% of furnace slag replacement by sand can work efficiently for the practical purpose.

Afolayan and Alabi (2013) observed the capacity of cupola slag in concrete. On further investigation he noted that the compressive strength of the concrete is calculated using two types of slag i.e. blast cupola furnace slag and granulated cupola slag by using it as coarse aggregate and further on partial replacement of cement was studied. A series of various experimental studies were organized which involves production of concrete in two stages. In the case of first stage which consists of Normal Aggregate Concrete (NAC), which in turn is produced with normal aggregates and cent percent Ordinary Portland Cement (OPC). Whereas, the second stage consists of production of concrete which in turn comprises of cupola slag as an aggregate with cent percent Ordinary Portland Cement (OPC) as shown in **Fig. 2.2** and can be seen with 2%, 4%, 6%, 8% and 10% as well i.e. the replacement of cementitious properties containing properly grinded cupola slag and further which is milled to less than 75 μm in diameter. Looking from the point of view of outcome of the compressive strength test which was conducted on the Slag Aggregate Concrete (SAC) which was having with and without grinded slag cementitious replacement conditions that shows that they were satisfactory as compared to that of Normal Aggregate Concretes (NAC).

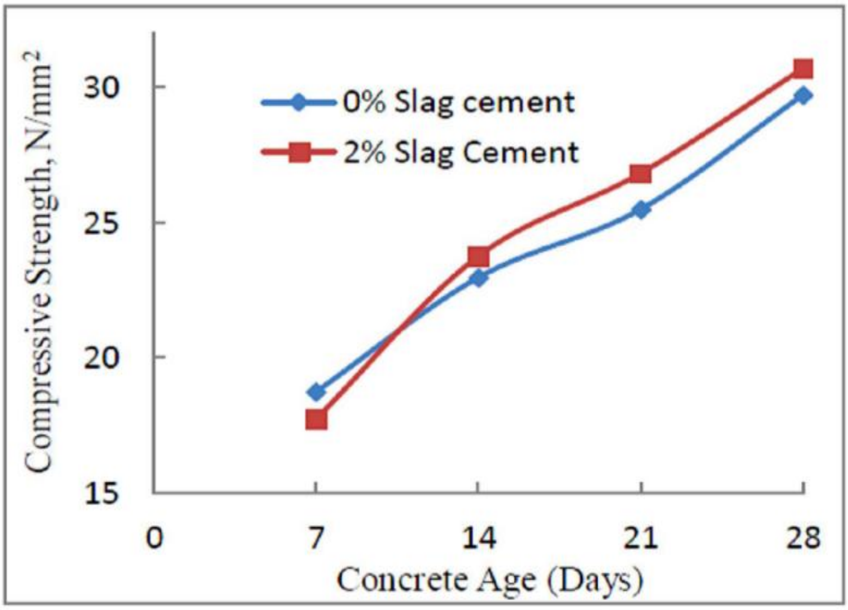


Fig.2.2 Comparison shown of slag aggregate concrete (SAC) having with and without slag cementitious replacement condition *(Afolayan and Alabi (2013))*

Arum and Mark (2014) concluded from the results on further investigation that the capability of cupola slag on being used as a partial replacement option instead of Ordinary Portland cement in case we require low permeability concrete. He even worked upon the chemical analysis part of Granulated Cupola Furnace Slag (GCFS) which consists of its fineness, bulk density, specific gravity, and even the standard consistency and setting time of OPC and GCFS pastes on which it was conducted. Moreover, he even produced concrete mixes of 0.55 water/cement ratio (w/c), which was achieved by keeping 1:2:4 ratio as volume basis at 0%, 5%, 10% and 15% replacement levels for OPC by using GCFS and thus parameters such as workability and permeability of concrete was determined. On an average they casted 36 cubes having 150mm as dimension from all sides and is kept for curing at 7, 21 and 28 days and further crushed to determine the compressive strength of cubes. Results obtained from the test shows that the on replacement of OPC within the defined range, shows that the compressive strength of concrete is generally showing an increasing trend at all the curing period and further on increasing the replacement level of OPC we observed that a maximum value of 29.8 N/mm2 is obtained at 28 days for 15% replacement of OPC, which further tends to increase to 31.9% more as compared to the strength obtained from controlled concrete.

2.3 UTILIZING OF CUPOLA SLAG AS A BEDDING MATERIAL FOR ROAD

Jones (2004) observed experimentally that the base course of a road is generally a layer which is used for the purpose of providing stability and support to all the upper layers or surface ones. The base course is usually made up of well compacted aggregate, asphalt, and even includes concrete. For this purpose, slag was crushed to make aggregates out of it and then they were tested and from the results obtained it was proved that it can be used as a base course material as it has good quality, moreover no other base course material was offering quite a large number of advantages as compared to slag. Thereafter the density of slag was coming out to be approximately 2.0 T/m^3, whereas in case of other slag such as steel furnace slag was approximately 2.6 T/m^3. When we compare all these factors in case of normal aggregates it comes in the size range of 2.1 to 2.3 T/m^3. From the experimental results it has shown that slag is better when it comes to wear resistance and along with this it requires less maintenance and is completely stable when it comes to various moisture conditions. Moreover, bases formed from slag aggregate has better drainage as compared to the one formed from natural aggregates with almost similar grading size considering shape of the aggregates as well. The depth of the base course is further reduced when slag aggregate was used because of the reason of its high strength.

Andrews et al. (2012) collected samples of cupola slag from two small scale foundries named as (Horoos and Abudia foundries) which are located in the place named as Kumasi metropolis. In order to determine the chemical composition of the slag, he used X-ray fluorescence spectroscopy. Further on investigating about the slag he acknowledged that the slag was free from various compounds such as CaO and MgO and thus can be used for road bed construction.

2.4 UTILIZATION OF CUPOLA SLAG ACTING AS AN INSULATING MATERIAL

Jones (2004) stated that the furnace slag consists of many other components of mineral wool and thus it is a principal raw material for the manufacture process. In order to achieve the purpose few other minerals are even mixed with coarse slag, in combination with coke acting as a fuel source, and further melted in a cupola furnace, by enforcing air in it to burn the coal. The liquid is then metered out through a restricted opening over high speed rotating cylinders that throw it part mixes in the air, leading to formation of fibers that in return solidify and further fall on a pile or on a moving conveyor belt in order to lead to the formation of blanket. Moreover, this fibrous product, will either be in bulk or in blanket form, thus it is an absolutely non-flammable inert insulation material which has high resistance to heat, and is thus usually used in pressed ceiling tiles.

Joulazadeh (2010) observed that the slag can even be used as an insulating material, which is known as slag wool. It is manufactured by further addition of auxiliary raw materials to the air-cooled furnace slag, and on adjustment of other components, thereafter melting of the mixture in a cupola furnace or an electric arc furnace is done and thus finally fiber combine it with the other special devices such as spinner. Moreover, the fibers are further elongated with the help of jet of air, steam or flame. The product formed is cured in the ovens and is thus formed into the familiar insulation blankets or thus cut into loose-fill insulation so that can be used at home, at commercial places and in industrial building as well. The process of manufacturing of slag wool is shown in **Fig.2.3.**

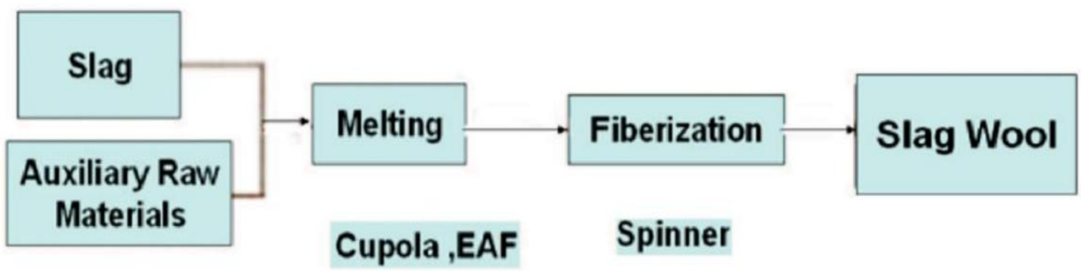


Fig.2.3 Manufacturing process of slag wool ***(Joulazadeh (2010))***

When it comes to usage of slag wool, it has a wide range of applications which includes acting as a heat insulating material, fire-proof wall material in construction of houses, moreover it even helps in reserving heat and sound absorption materials which is used for industrial applications. The fibers formed are non-combustible and usually have melting point over 1100°C, and thus they are used against protection from fire.

2.5 UTILIZATION OF SLAG IN GLASS CERAMICS

Agarwal and Speyer (1992) observed that the impact on the environment and the economic considerations led to further exploration of various technologies that allow us to use slag as a raw material for the commercial products. The experimental work done by the author gave procedure for further production of the glass ceramics which is based on the blast furnace slag.

Salman and Darwish (2005) discussed the utilization of slag for the purpose of production of glass ceramics. The furnace slag is generally influenced due to devitrification to the extent that no as such monolithic glassy phase can be obtained even if the granulation process has occurred. Further, composition for a glass-ceramic one requires more ability for formation of glass and can control its further crystallization process into a favorable one fine-grained microstructure. Moreover, in order to get a stable glass from the slag as a result, thus it becomes necessary to further decrease the diffusion rate throughout the slag which is based on glass and is obtained by increasing its viscosity. This may lead to the reduction either rate of nucleation or crystallization and in order to ensure this or at least minimize the temperature zones which result in their overlapping. Thereafter the addition of granite to the cupola slag is satisfying all the requirements.

2.6 UTILIZATION OF SLAG IN CEMENT PRODUCTION

Kumar et al. (2006) discussed about the cement industry which is basically a material and energy intensive industry. He observed that usually 1-1.5 tonnes of limestone and further 0.5 tonnes of coke are used for the production of per tonne of clinker. Talking about the specific energy consumption in case of cement manufacturing process sums upto 4000 MJ/tons of cement which is having nearly 80% of the contribution which is arising from the thermal energy (usually for clinker formation) and the rest is from electrical energy i.e. major contribution is arising from grinding. Additionally, 0.8 to 1 tons of CO_2 is generated on per tons basis of the clinker formation. Further on replacement of clinker with that of the industrial waste, such as fly ash and it even includes granulated blast furnace slag which is usually used all over the world and thus helps in the conservation of resources, further reduces energy consumption and thus helps in minimizing emission of CO_2. Moreover, the type of cement which uses fly ash and granulated blast furnace slag as a partial replacement of the clusters is called as blended cement. India being, the second largest producer of the cement when it comes to the world ranking. Looking at its current levels of production further exceeding approximately 110 million tonnes on annual basis, in the world ranking country ranks only after china. In India, generally blended
cements consist of 20–25% fly ash, and approximately 40% blast furnace slag are usually produced. Therefore, the fly ash and the slag which is produced in the country sums up to 110 million tonnes

and 12–15 million tonnes for the slag, respectively. Moreover 10- 12% fly ash and 40–50% of slag is usually used in blended cement for the manufacturing process and there is even scope for further increase in the utilization of usage of these wastes in the manufacturing of blended cement.

Joulazadeh (2010) concluded that the Cement Company named as Sepahan was established in 1969 in the nearby vicinity to the ESCo plant and it has been further employing two production lines for the purpose of production of Portland cement which is using slag of ESCo blast furnaces. When we discuss about BF slag cement it has almost 20-40% slag content present in it and is used for general construction purpose. The blast furnace slag cement which is having higher content of BF slag is usually used where heat of hydration is required to be minimum, further it helps in increasing resistance against chloride ion, or sulphate or sea water attack, and it is necessary, or to reduce the chances of occurrence of aggregate reaction. The company we have discussed above uses almost 15% of the BF slag in the formation of cement products. On an average it has cement production capacity to almost 2.5 million tonnes as annual production. The main characteristics of the BF slag they were using are:

1. It is suitable for the erection purpose of massive concrete constructions of which few examples are as such dams due its capability to exhibit low heat of hydration.
2. It is even suitable for the sewage facilities and offshore constructions.
3. On long term strength basis, it has shown better results than that of Portland cement.
4. It is usually effective in controlling the alkali aggregate reaction.
5. ·It has shown better water resistance in comparison to Portland cement because of its higher compactness of hardened concrete.

2.7 UTILIZATION OF SLAG AS ROOFING MATERIAL

Jones (2004) stated that the furnace slag is generally preferred in comparison to other products for using it in the building roof system i.e. where aggregate is used to protect and prevent the bitumen present at the roof from the various effects of the weather. The blast furnace slag provides us with capability of greater bonding with that of roofing bitumen as compared to that than of the normal aggregates. When we discuss durability of the furnace slag it is excellent, and it even performs well in case of freezing and thawing and further shows better result for sulphate soundness tests as well. The furnace slag is usually light in weight; have high reflectivity and compared to the conventional one it has better insulation value, and even higher fire resistance for the purpose of usage in building up roofing systems.

Hutchinson (2010) have acknowledged about the process of production of stone wool. The main components of stone wool are basalt stone and furnace slag, with slag being a waste product of the steel industry and iron industry. The stone wool has found is mostly recycled up to 40% in few cases. The process of formation is generally a complex process which comprises of converting the rock in raw form and then further slag into stone wool and as result of this a product is likely possible for providing thermal, fire, and even sound resistant properties, which are all coming out as dimensionally stable and thus providing an appropriate surface for roofing purpose.

2.8 USAGE OF FURNACE SLAG AS AGRICULTURAL LIMING MATERIAL

Joulazadeh (2010) said that the furnace slag has been utilized as the basic main material acting as a raw material for silicate fertilizers. Moreover, blast furnace slag consists of few components of fertilizer such as lime, magnesia and even the one as Fe and B, silicate fertilizers, also known as silicate-calcium fertilizers which are generally known for its good result with aquatic rise. For other agricultural things such as farms lime, magnesia and even silicates which are abundantly present in BF slag, thus help in improving the chemical properties of soil. The major advantage for farmers use agricultural slag for the purpose of maximum yielding of cultivated crops and used even for pastures purpose. It can even be used in Parks, golf courses or lawns whose basic need is to correct soil acidity, for the purpose of ensuring the optimum benefit of applied fertilizer. As agricultural slag keeps on flowing easily though lawn spreads. In case of nurseries and greenhouse they prefer using agricultural slag in order to make soil rich for plant beds and thus strip mining even need a liming material for the purpose of neutralizing high soil acidity.

National Slag Association, US concluded that the benefit of slag to the crop production and even to the soil fertility which is having adequate levels of alkalinity present in it. People on general basis in case of various type of cultivation which is done after a fixed span, even add liming material to the soil in order to attain desired PH value. They even identified the need for further addition of few minor elemental nutrients, named as boron. The test directed on soil helps in deciding what number of tons per section of land of liming material and supplements to apply. In regions where iron and steel are fabricated, a horticultural impact heater slag item might be accessible as an efficient other option to agrarian limestone or dolomite and as a superior wellspring of minor supplements. Ag-Slag is more regularly coarser than limestone however ought to be satisfactory to keep up appropriate levels of soil PH. The corrosive soil issue can be redressed by utilizing a better reviewed farming slag material. It is additionally simpler to spread, especially in a moist condition. Since agricultural slag adjusts soil acidity by a somewhat unique chemical reaction, the CCE test method in ASTM C-602 particular, Agricultural Liming Materials, is somewhat unique for slag than it is for limestone, as prescribed by the Association of Agricultural Chemists. In light of soil tests and the coveted product, the application of a magnesium-bearing, liming help is normally prescribed. By and by, Ag-Slag with 10-14% magnesia (MgO) is adequate.

2.9 USE OF SLAG AS SLURRY SEALS

National Slag Association, US distributed that the slurry seals were created, in the late 1920's what's more, the mid 1930's. Utilizing a black-top emulsion with a fine total and filler, a "slurry" or semi fluid blend was readied, for the most part in a travel blend truck. In 1960, the main economically accessible self-contained machine to ceaselessly blend and spread slurry seals was set in activity. This allowed snappy proportioning, blending, and setting of the slurry before the emulsion began to break, in this way enhancing grip to the old surface. Three sorts of slurry seal blends are normally utilized with varieties in total reviewing, black-top substance and application rate. Sort I total mix is utilized to seal breaks, fill little voids, and right direct surface decay as well as general drying or solidifying of surface black-top. Sort II total mix is the most ordinarily utilized in slurry seal work and most intently compares to the evaluating of most slag screenings. They are utilized when it is wanted to fill surface voids, revise surface disintegration and raveling, and give fixing and a thin wearing surface. Sort III total mix utilizes totals up to 3/8" in estimate and are connected at rates over 15 lb./sq. yd. Significant applications are for to a great degree unpleasant finished asphalts where a bigger size of total and a more prominent slurry thickness are important to fill in the voids and give a direct thickness wearing course. They may likewise be utilized as a part of two course development to remedy the crown in an asphalt or to give a wearing course on different sorts of balanced out bases including soil concrete.

2.10 CONCLUSIONS DRAWN FROM THE LITERATURE REVIEW:

From the literature part, it is clearly depicted that a considerable measure of work has been done in this field. Following are the focuses which can be concluded from the literature written above:

1. The slag can be used as a substitution material in all types of concrete. Amid the experimental tests, it has been discovered that the substitution of both coarse and fine aggregates with slag would result in increment in the compressive and tensile strength of cement by 4% to 6%.

2. The investigation of chemical and mineralogical properties of the cupola furnace slag affirms that it can be helpful as a road bed material instead of using it for improving soil fertility improper.
3. The slag can be utilized as a raw material for the generation of slag wool alongside the utilization of other raw materials. The slag fleece is completely non-combustible having high resistance to heat thus, can be used as a part of modern structures.
4. The slag can likewise be used in the development of blended cement as a partial substitution to the clinker, which is used for the production of cement. The examination done on the utilization of slag in the development of blended cement shows that 40 to 50 % slag is used as a partial substitution to the clinker material which uses the slag as well as monitor the normal assets which are generally required for the creation of clinkers.
5. The blast furnace slag can be substituted as a raw material for enhancing the fertility of soil as it contains the manure constituents, for example, lime and iron. Additionally, it can be utilized to improve the chemical properties of soil and it can likewise help in enhancing the soil texture.
6. The slag can be used as slurry seals which is a sort of semi liquid blend utilized to seal the cracks, fill little voids and correct minor surface decay present on the road surface.

The goal of the present examination is to use the Cupola furnace slag, acquired from the foundry industry accessible in Punjab, as a substitute to fine aggregates in concrete and to consider the impact on compressive and split tensile strength of concrete. The chemical composition of cupola slag differs broadly relying on the coal quality, defilement of charging material and amount and nature of lime stone utilized as a part of furnace. In this manner, there is a need to think about the composition of furnace slag before replacing it to a few percentages with the fine aggregates.

CHAPTER - 3

EXPERIMENTATION

3.1 GENERAL

The present part describes the materials properties and the outcomes acquired from the different tests directed on the material utilized for the development of concrete mixes containing cupola furnace slag as partial substitution of fine aggregates. With a specific end goal to accomplish the objective of the research, an experimental program was directed to study the compressive strength, split tensile strength, water permeability and abrasion resistance of materials made by utilizing the prescribed materials in composed extents. The experimental technique has been utilized to decide the impact of cupola slag on the compressive and split tensile strength of concrete, in addition to the durability properties of abrasion resistance and water permeability.

3.2 MATERIALS

The properties of different materials utilized as a part of the examination are resolved according to the relevant codes of practice ***(Gambhir, 1992).*** The different materials utilized are concrete, coarse, fine aggregates and cupola slag. The point is to check their approval with the code necessities and to empower a designer to outline a solid blend for a specific quality.

3.2.1 ORDINARY PORTLAND CEMENT (OPC 43)

Cement is the most essential element of the concrete mix as it acts as binder material between the coarse and fine aggregates. It was developed from other types of hydraulic lime in the mid-19th century, and usually originates from limestone. It is a fine powder, produced by heating limestone and clay minerals in a kiln to form clinker, grinding the clinker, and adding 2 to 3 percent of gypsum. Several types of Portland cement are available. But the most common type, is known as Ordinary Portland Cement (OPC), which is grey in color, but even white Portland cement is also available. It might be further talked about as siliceous and aluminous material which has almost no cementitious properties yet will, in finely divided form and within the presence of moisture, and further chemically respond or react with calcium hydroxide at ordinary temperature which will lead to the formation of compounds having cementitious properties. It is usually in a finely separated state as it is at exactly that point that silica can join with calcium hydroxide in the presence of water in order to form a stable calcium silicates which have cementitious properties. The cement utilized for the present investigation is OPC Ultra-tech concrete and it is protected from dampness to prevent the deterioration in its properties. The cement utilized is fresh and free from protuberances. The different tests conducted on cement are specific gravity, soundness, initial and final setting time and compressive strength. The results of the said tests performed on the cement are given in Table 3.1.

Table 3.1 Physical properties of cement

S. No.	**Properties**	**Values obtained**
1	Specific gravity	3.14
2	Fineness of cement (% retained on 90μm sieve)	5.75 %
3	Initial setting time	95 minutes
4	Final setting time	400 minutes
5	Compressive strength	
	3 days	22.25 MPa
	7 days	31.67 MPa
	28 days	41.83 MPa

3.2.2 COARSE AGGREGATES

Coarse aggregates are inactive granular materials having size more than 4.75mm. They can either be from primary, secondary or reused sources. Primary aggregates are collected either from earth or from the marine condition. Coarse aggregate incorporates fragments and crushed pieces. Fragments or gravels constitute the dominant part of coarse aggregates utilized as a part of cement with crushed stone making up a large portion of the remaining. Secondary aggregates are materials which are the results of extractive tasks and are obtained from an extensive variety of materials. Reused concrete is a reasonable source of aggregate and has been agreeably utilized as a part of granular sub bases, soil-cement, and in fresh concrete.

The coarse aggregates utilized as a part of the present work is having the greatest size of 20 mm and even using 10 mm aggregates as well and they are appropriately washed to make it soil free before performing out the test for deciding its physical properties. The different properties tested are specific gravity, water absorption and sieve analysis. The outcomes acquired are as such presented in **Tables 3.2, 3.3, 3.4, 3.5**.

Table 3.2 Physical Properties of Coarse aggregates (20 mm)

S.No.	Physical Properties	Values obtained
1	Specific gravity	2.69
2	Water absorption	1.4%
3	Color	Grey
4	Largest size	20 mm

Table 3.3 Fineness Modulus of Coarse aggregates (20 mm)

S.No.	Sieve No.	Weight retained (gm)	% retained	% passing	Cumulative weight Retained (%)
1	20	363	3.63	96.37	3.63
2	10	8890	88.9	7.47	92.53
3	4.75	747	7.47	0.00	100
4	2.36	0	0.00	0.00	100
5	1.18	0	0.00	0.00	100
6	0.6	0	0.00	0.00	100
7	0.3	0	0.00	0.00	100
8	Pan	0			

Fineness modulus (20 mm) coarse aggregates = 6.95

Table 3.4 Physical Properties of Coarse aggregates (10 mm)

S.No.	Physical Properties	Values obtained
1	Specific gravity	2.62
2	Water absorption	1.72%
3	Color	Grey
4	Largest size	10 mm

Table 3.5 Fineness Modulus of Coarse aggregates (10 mm)

S.No.	Sieve No.	Weight retained(gm)	% retained	Cumulative wt. Retained (%)
1	20	0.00	0.00	0.00
2	10	3650	36.5	36.5
3	4.75	6350	63.5	100
4	2.36	0	0.00	100
5	1.18	0	0.00	100
6	0.6	0	0.00	100
7	0.3	0	0.00	100
8	Pan			

Fineness modulus (10 mm) coarse aggregates = 6.36

3.2.3 FINE AGGREGATES

Fine aggregates are fundamentally sand acquired from the land or the marine condition. Fine aggregates consist of smaller or larger particles of regular sand or crushed stone with most particles passing through 4.75 mm sieve. Similarly, as with coarse aggregates these can be from primary, secondary or reused sources. The different properties evaluated are specific gravity, water absorption and sieve analysis. The results got from the said tests are given in **Table 3.6 and 3.7**.

Table 3.6 Physical Properties of Fine aggregates

S.No.	Physical Properties	Values obtained
1	Specific gravity	2.65
2	Water absorption	2.6%
3	Zone	II

Table 3.7 Fineness Modulus of Fine aggregates

S.No.	Sieve No. (mm)	Weight retained (gm)	% retained	% passing	Cumulative weight Retained (%)
1	4.75	31	3.1	96.9	3.1
2	2.36	137	13.7	83.2	16.8
3	1.18	238	23.8	59.4	40.6
4	0.6	168	16.8	42.6	57.4
5	0.3	316	31.6	11	89
6	0.15	65	6.5	4.5	95.5
7	Pan	45	4.5	0	

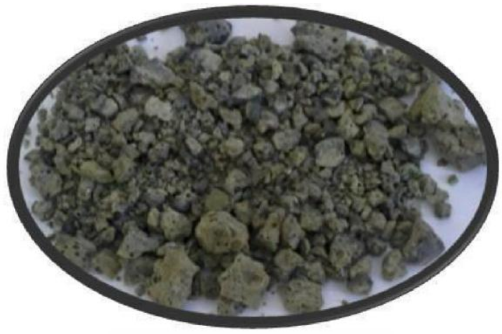
Fineness modulus of fine aggregate = 2.96

3.2.4 CUPOLA SLAG

It is generally dense in nature and along with this it has solid structure and further shows qualities of vitrified material. Its color variation is usually from grey to dark brown. Moreover, if the cupola slag is lighter in color then the slag possesses higher basicity as compared to the other slag. Thereafter, if the slag has appeared to be darker in color then it may have aroused due to oxidizing conditions presence in the furnace itself. It is usually done by two methods – Conventional method in which traditional method of breaking down of slag into smaller fragments is followed whereas in case of Wet granulation method water stream is used for obtaining smaller fragments.

The furnace slag used herein for testing purpose is collected from the mentioned foundry clusters of Punjab *i.e.* M/s Greatway Foundry and Engineering Works, which is located at Batala, M/s Joshi Motor Parts, situated at Jalandhar and M/s Makhan Sewing Machine, which is situated at Ludhiana in order to visualize the nature and further analyze chemical composition of cupola slag. **Fig.3.1** shows us that there is variation in terms of size and color of the cupola slag due to the difference in the way of operating and even quality of the material which is being used in the cupola furnace.

i **) Batala slag sample**

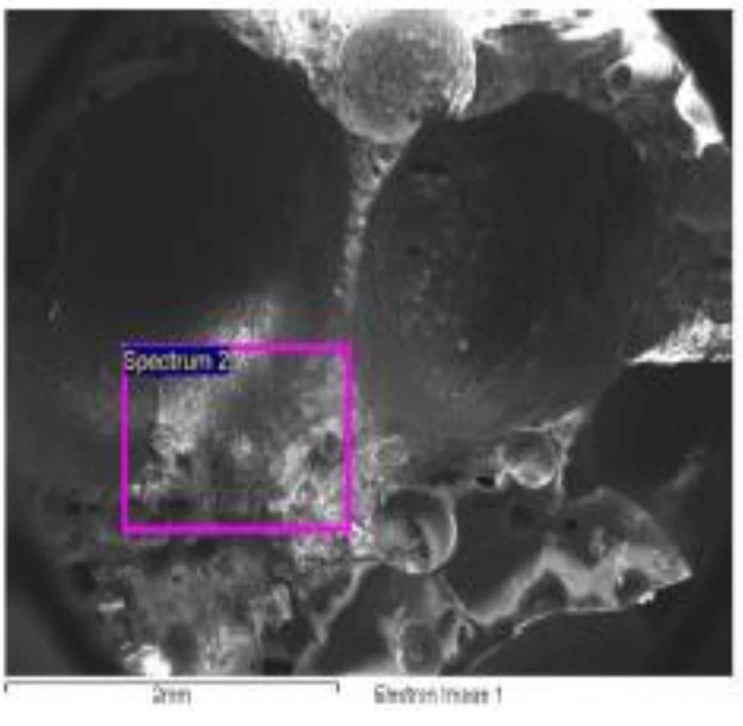


ii) Jalandhar slag sample **iii) Ludhiana slag sample**

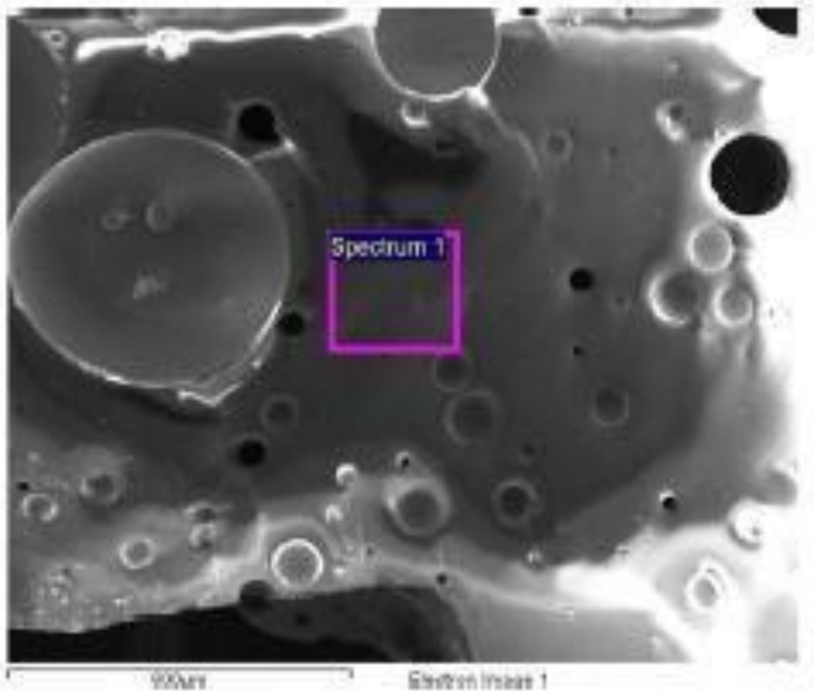
Fig.3.1 i) Batala ii) Jalandhar iii) Ludhiana slag samples

Testing of these slag samples were conducted at SAI Labs, present within TIET, Patiala for Scanning Electron Microscope (SEM) analysis, which is shown in Fig. 3.2.

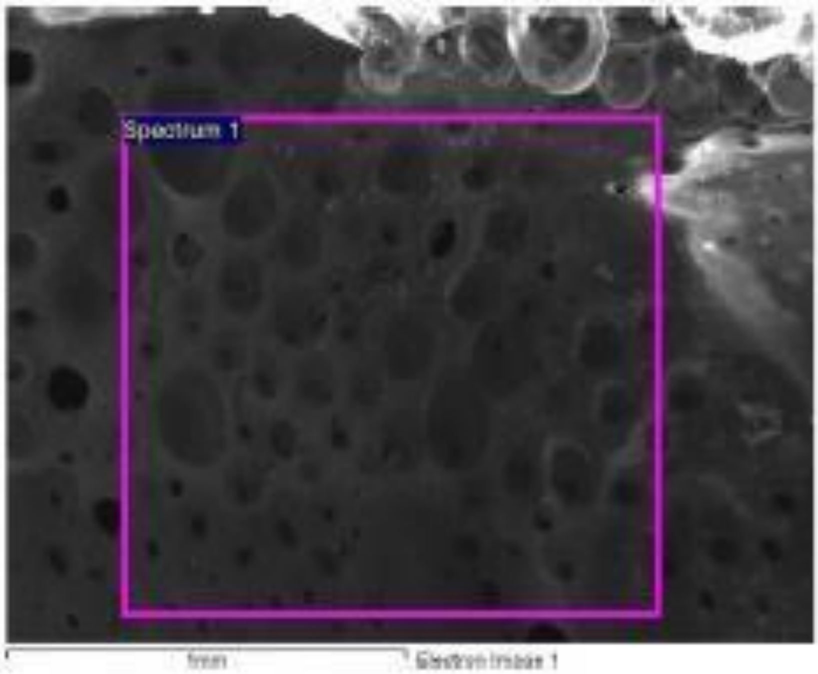
The results obtained from the SEM analyses are shown in Fig. 3.3. The analyzed detailed description of chemical composition of slag samples are given in Table 3.8.



i) Batala slag



ii) Jalandhar slag



iii) Ludhiana slag

Fig.3.2 SEM results i) Batala ii) Jalandhar iii) Ludhiana slag samples

Table 3.8 Chemical composition of batala slag samples

Sr. No.	Compound	Weight (%)
1.	MgO	7.37
2.	Al_2O_3	12.67
3.	SiO_2	48.76
4.	SO_3	0.14
5.	K_2O	1.38
6.	CaO	14.09
7.	FeO	15.59

Table 3.9 Chemical composition of Jalandhar slag samples

Sr. No.	Compound	Weight (%)
1.	MgO	8.98
2.	Al_2O_3	16.02
3.	SiO_2	47.09
4.	SO_3	0.38
5.	K_2O	0.89
6.	CaO	11.12
7.	FeO	15.53

Table 3.10 Chemical composition of Ludhiana slag samples

Sr. No.	Compound	Weight (%)
1.	MgO	4.80
2.	Al_2O_3	8.77
3.	SiO_2	22.85
4.	CaO	16.58
5.	FeO	4.33
6.	CO_2	42.66

The chemical composition of the distinctive or various cupola furnace slag sample changes and this variety in the slag quality relies upon numerous elements, for example, nature of coal, contamination of charging material and amount along with quality and further in addition nature of lime stone utilized forming a part of furnace. The chemical composition uncovers that quantities acquired for Batala slag test which consists of SiO_2, CaO, MgO and Al_2O_3 was lying in the nearby values of the quantities obtained for Jalandhar and Ludhiana slag from tests. In this way, the Batala slag was considered best out of all other slags, thus carrying out further main study with this slag only. The different physical properties of cupola furnace slag examined are specific gravity, water absorption and sieve analysis. The results are observed are mentioned in Table:

Table 3.11 Physical Properties of Ludhiana Slag

Sr. No.	Physical Properties	Values obtained
1.	Specific gravity	1.74
2.	Water absorption	1.61%
3.	Color	Light Grey

Table 3.12 Fineness Modulus of Ludhiana Slag

Sr. No.	Sieve No. (mm)	Weight Retained (gm)	% Retained	Cumulative Weight Retained (%)
1.	4.75	11.5	1.15	11.5
2.	2.36	405.5	41.7	417
3.	1.18	190	60.7	607
4.	0.6	69.5	67.6	676.5
5.	0.3	166.5	84.3	843
6.	0.15	97.5	94.1	940.5
7.	Pan	59.5		1000

Fineness modulus of Ludhiana slag = 3.4

Table 3.13 Physical Properties of Jalandhar Slag

Sr. No.	Physical Properties	Values obtained
1.	Specific gravity	2.24
2.	Water absorption	1.50%
3.	Color	Light black

Table 3.14 Fineness Modulus of Jalandhar Slag

Sr. No.	Sieve No. (mm)	Weight Retained (gm)	% Retained	Cumulative Weight Retained (%)
1.	4.75	10.5	1.1	10.5
2.	2.36	403.5	41.88	414
3.	1.18	241	66.26	655
4.	0.6	95	75.87	750
5.	0.3	86	84.57	836
6.	0.15	117.5	96.5	953.5
7.	Pan	35		988.5

Fineness modulus of Jalandhar slag = 3.6

Table 3.15 Physical Properties of Batala Slag

Sr. No.	Physical Properties	Values obtained
1.	Specific gravity	2.45
2.	Water absorption	1.45%
3.	Color	Dark black

Table 3.16 Fineness Modulus of Batala Slag

Sr. No.	Sieve No. (mm)	Weight Retained (gm)	% Retained	Cumulative Weight Retained (%)
1.	4.75	4.5	0.45	4.5
2.	2.36	300	30.5	304.5
3.	1.18	285.5	59.1	590
4.	0.6	183	77.4	773
5.	0.3	123.5	89.7	896.5
6.	0.15	77.5	97.5	974
7.	Pan	22		996

Fineness modulus of Batala slag = 3.52

3.3 TESTS CONDUCTED ON MATERIALS

The following subsections describes the test methodology for finding the physical properties of various materials such as Portland cement, Coarse aggregates, Fine aggregates and Cupola slag according to prescribed manual (Gambhir, 1992).

3.3.1 SPECIFIC GRAVITY

Specific gravity is the proportion of the heaviness or weight of a given volume of substance to the heaviness of an equivalent volume of some reference substance or proportionately the proportion of the majority of equivalent volume of two substances.

3.3.2 SIEVE ANALYSIS

The sieve analysis is performed to decide their particle size distribution or estimate the conveyance of coarse and fine aggregates by sieving and discovering their fineness modulus subsequently.

3.3.3 COMPRESSIVE STRENGTH

The cube samples of size 150mm x 150mm x 150mm are casted for testing of compressive strength of concrete and are shown in **Fig. 3.3** for better understanding of test being conducted. The materials used while casting of the samples are as such i.e. cement, coarse aggregates (10 mm and 20 mm), fine aggregates and cupola furnace slag are legitimately weighed according to the appropriate mix design for various water cement ratios (w/c) such as 0.4, 0.45 and 0.5, thus all materials are blended to get the uniform blend. The amount of water included the dry blend is in accordance to the already decided mix proportion in order to obtain the mix in the desired slurry form. The concrete mixture is filled in the cube shaped moulds which are further vibrated to guarantee the appropriate compaction. The top one surfaces of the form are legitimately finished by proper usage of trowel. The properly finished samples were left to solidify in air for a time period of 24 hours. The samples are then taken out from the cube moulds after completion of 24 long hours and afterwards letting cubes to be cured in the water tanks for a time period of 7, 28 and 56 days and then noticing down its values and further making conclusions out of it.

Fig. 3.3 Cube samples in moulds

The cube samples in this case are casted for various water cement ratios (0.4, 0.45 and 0.5) by partial replacement of the fine aggregates with cupola furnace slag up to percentage of 10%, 20%, 30% and 40%. The samples are tested for compressive strength of the material at particular mix design after curing of samples for the time period of 7, 28 and 56 days. The sample is then placed on compressive testing machine having capacity of 5000 KN for checking its compressive strength and moreover the load application process on sample is a gradual one and is continued till the failure of sample is obtained thus obtaining strength at that point. The process of calculating compressive strength is shown in **Fig. 3.4**.

Fig. 3.4 Compressive strength testing of cube

3.3.4 SPLIT TENSILE STRENGTH

The split tensile strength of concrete is calculated by using cylinders which is having dimension as 150 mm X 300 mm and is shown in **Fig. 3.5** and **Fig. 3.6**. Materials used for the casting purpose is same as in case of compressive strength and the only difference which lies is that in case of compressive strength cubes are casted whereas in case of split tensile cylinders are being casted. The material used is as such i.e. cement, coarse aggregates, fine aggregates and cupola furnace slag which are weighed according to the computed mix design for various water cement ratios and thus altogether blended in order to get the desired mix. The amount of water which is required to be added to the cement present in dry form, according to the particular mix design and thus obtaining required cement paste. The concrete mixture is being filled in the cylindrical moulds which are vibrated in order to obtain proper compaction. The best surface of the cylinder is appropriately finished up by making required use of trowel. The completed samples were left to solidify in air for a time period of 24 hours. The samples are taken out from the cylindrical moulds, following 24 long periods of being placed in water tank for curing period of 7, 28 and 56 days.

Fig. 3.5 Testing of cylindrical specimen

Fig. 3.6 Casting of cylindrical specimens

The cylindrical samples are in this case casted for various water-cement ratios by partial replacement of fine aggregates with that of cupola slag till extent of 10%, 20%, 30% and 40%. The samples are then tested for split tensile strength after placing the samples for curing time of 7, 28 and 56 days. The amount of tensile stress acting consistently to the line of action of the load being applied in a direction perpendicular to the sample tested is given by:

$$T = \frac{2P}{\pi D L}$$

In the above equation:

P = Load applied (KN)

D = Diameter of the cylindrical sample (mm)

L = Length of the sample (mm)

The sample is tested in the Compressive Testing Machine (CTM) and the load is applied on a constant rate so that no deformation is observed before actual failure is observed and thus calculating split tensile strength of the sample.

3.3.5 WATER PERMEABILITY TEST

Water permeability is a genuine indicator of penetrability of water in concrete. In this test, usually estimation of penetration depth is measured for the continuous water stream which is being ascertained by a constant pressure head. The test directed according to German standard DIN (Part 5). The test setup basically comprises of following parts: water source with controller, water infiltration cell and arrangement in order to control course of action when additional pressure is applied (i.e. Pressure controller) and cubes of size 150mm x 150mm x 150mm are prepared as shown in the **Fig. 3.7**. At once, three specimens can be evaluated.

The technique to perform this permeability test starts off by filling the source of the water in the apparatus upto 75% of its capacity. The water level in the glass tube is clearly visible, which in turn is placed on the stand. Presently, put the samples in the penetration cells, in order to start with the test on the right time and preferably try to test samples almost within 30 minutes of removal of samples from the curing tanks. Place the sample in such way that the casted surface is almost in a direction perpendicular to the surface being tested. The cast surface ought to be vertical. Fix the four screws present on the cell to give a tight fit to the samples in the cells. Do ensure that the screws are not tightened too much. Ensure there is no spillage. Now, open the valve in order to allow the stream of water and set the pressure to 5 Kg/cm^2 utilizing pressure controller. A constant pressure is applied on the samples for 3 days (72 hours) with the same arrangement in order to manage the pressure. Following 3 days, discharge the water pressure and evacuate the test samples further dividing the sample into two equal parts so that it is easy for examination purpose as appeared in **Fig**. **3.8**

Inside a moment in the wake of splitting, try marking the front surface having water mark on it and for proper visibility you mark the area bit darker. Do take care of the fact that if the cut face of the sample is left for an extensive stretch, then it may dry. The maximum depth of penetration of water can be measured by using scale which in turn is basically a durability factor and such methods are used for measuring it. Progressively, if the depth of penetration of water goes on increasing then decrease in strength of concrete is observed. This can be utilized for comparison in terms of potential durabilities of different kinds of concrete. Thereby, utilizing water penetration depth for comparison purpose.

Fig. 3.7 Water permeability apparatus

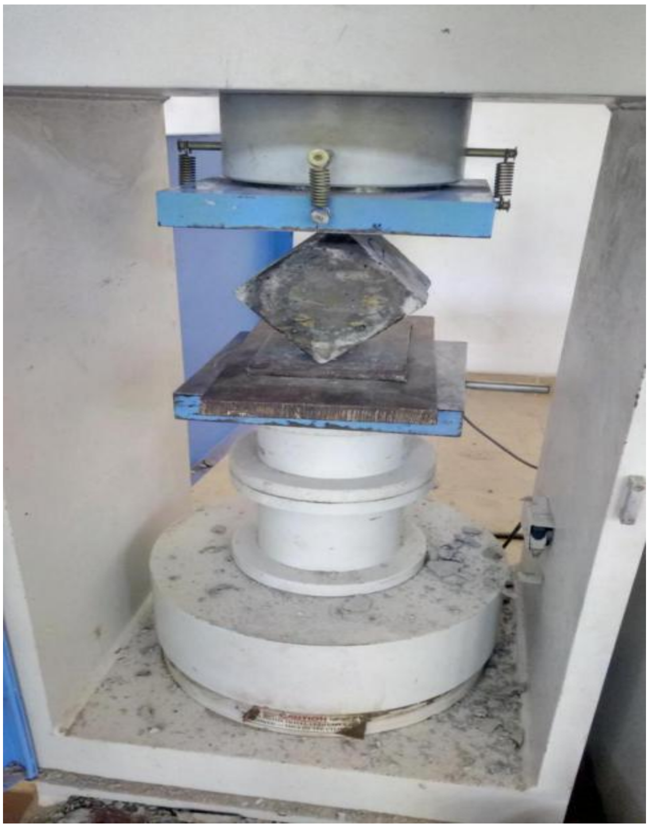


Fig. 3.8 Testing of water permeability sample

3.3.6 ABRASION RESISTANCE TEST

Abrasion Resistance test of concrete is usually conducted in accordance with IS 15658:2006. For carrying out this test, samples of dimensions 70mm x 70mm x 25mm were casted. The contact face and the contrary face of the specimen will be parallel and levelled. For finding out the decrement in the thickness, the contrary face will, if fitting, be ground parallel or generally machined in order to be parallel. For testing dry samples, the samples will be dried to achieve the constant mass at a temperature of 105 ± 5 °C.

The method for directing the test is: Firstly, measure the sample on the exact measuring balance and weight of the sample will be noted closest to 0.1 gram. Similarly, density of the sample can even be calculated closest to the 0.1 gram. The grinding way of the disc of the abrasion testing machine will be equitably strewn with 20 grams of the standard abrasive powder. The sample will be settled in the holding frame in such a way that at the end the testing surface should face the granulating disc. The sample will be midway loaded with 294 ± 3 N.

Further the grinding disc will keep running at a speed of 30 rpm. The disc will be ceased after one cycle of 22 revolutions. The grinding disc and the contact face of the sample will be cleaned of grating powder and debris as well. The sample will be turned 90° in the clockwise way and along with these 20 grams of grating powder will be equitably strewn on the disc before beginning the following cycle. The test cycle will be done on repeated mode 16 times, moreover the sample being turned 90° in the clockwise way. Spreading of 20 grams of grating or abrasive powder is done on the track after each cycle. The testing machine for abrasion is presented in the fig. 3.9.

Fig. 3.9 Abrasion resistance testing machine

Further in the above study the grating powder used for the testing purpose is Aluminum Oxide Neutral (Al_2O_3) which is having pH within the range of 6.5-7.5.

3.4 MIX DESIGN

Mix design is basically calculated for various water cement ratios (w/c) which in turn are based on the different tests performed on the materials. The different mixes are calculated for already defined water cement ratios such as 0.40, 0.45 and 0.50. In similar manner the quantity of fine aggregates required as per the composition of the mix design is partially replaced by cupola furnace slag for the percentage replacement as 10%, 20%, 30% and 40%.

3.4.1 Mix design for various water cement ratio

Mix design is being calculated by the Indian standard code i.e. IS 10269, moreover on the basis of these codal provisions further calculations were made as shown.

Table 3.17 Mix design for W.C ratio (0.5)

Replacement ratio (%)	Water (Kg/m^3)	Cement (Kg/m^3)	F.A (Kg/m^3)	C.A (20mm) (Kg/m^3)	C.A (10mm) (Kg/m^3)	Cupola Slag (Kg/m^3)
0	172	344	725.49	720.9	466.36	-
10	172	344	652.94	720.9	466.36	66.54
20	172	344	580.39	720.9	466.36	133.09
30	172	344	507.84	720.9	466.36	199.64
40	172	344	435.29	720.9	466.36	266.19

Table 3.18 Mix design for W.C ratio (0.45)

Replacement ratio (%)	Water (Kg/m^3)	Cement (Kg/m^3)	F.A (Kg/m^3)	C.A (20mm) (Kg/m^3)	C.A (10mm) (Kg/m^3)	Cupola Slag (Kg/m^3)
0	172	382.22	694.35	720.02	466	-
10	172	382.22	624.91	720.02	466	63.7
20	172	382.22	555.48	720.02	466	127.38
30	172	382.22	486.04	720.02	466	191.08
40	172	382.22	416.60	720.02	466	254.77

Table 3.19 Mix design for W.C ratio (0.40)

Replacement ratio (%)	Water (Kg/m^3)	Cement (Kg/m^3)	F.A (Kg/m^3)	C.A (20mm) (Kg/m^3)	C.A (10mm) (Kg/m^3)	Cupola Slag (Kg/m^3)
0	180	450	647.11	700.63	453.25	-
10	180	450	582.4	700.63	453.25	59.35
20	180	450	517.69	700.63	453.25	118.71
30	180	450	452.98	700.63	453.25	178.07
40	180	450	388.26	700.63	453.25	237.43

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

The principle target of the present work is to investigate the quality attributes of concrete acquired after utilization of cupola furnace slag as partial substitution to fine aggregates. With a specific end goal to accomplish the objective, a test methodology was followed in order to examine the effect of cupola furnace slag on mechanical and durability properties of concrete samples. The test methodology comprised of casting, curing and testing of samples with and without usage of cupola furnace slag at various curing periods. The test process included:

1. Testing of various material properties.
2. Mix Design for different W.C ratios.
3. Casting and curing of samples.
4. Tests conducted to find the compressive strength, split tensile strength of samples
5. Tests conducted to observe values for water permeability and abrasion resistance of samples

The accompanying sections deal with the results which are obtained from different tests conducted on concrete samples which were cast with and without usage of cupola furnace slag.

4.2 COMPRESSIVE STRENGTH

In most auxiliary applications, concrete is generally utilized essentially to oppose the stresses occurring due to the compressive nature of concrete. At the point when a plain concrete member is further subjected to pressure in compressive form, the failure of the member will happen in its vertical plane along the diagonal one. The cracks in the vertical direction mainly occur due to the laterally occurring tensile strains. A minute stream in the concrete, which is generally in the form of miniaturized scale split expanding along the vertical axis of the concrete member, will happen on the utilization of axial compression load and thus will propagate because of the lateral tensile strains.

Usually three test samples of 150mm x 150mm x 150mm are cast for obtaining results of the compressive strength of concrete for various water cement ratios. The concrete mix which comprises of varying quantity of cupola furnace slag (which varies from 10% to 40%), as partial substitution to fine aggregates which were casted and were left for the curing period of 7, 28 and 56 days. The results which were obtained after testing of cube samples for the curing time of 7, 28 and 56 days are as shown:

Table 4.1 Compressive strength (Water cement ratio - 0.50)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.50		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	432.7	19.13	441.5	19.5	492	21.8	559.1	24.7	460.7	20.4
2		28	630.0	28.0	673.5	29.9	703.2	31.2	725.2	32.2	645.4	28.6
3		56	690.8	30.6	732.6	32.4	765.7	34.03	789.2	35.07	694.4	31.4

Table 4.2 Compressive strength (Water cement ratio - 0.40)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.40		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	564.0	25.06	643.5	28.6	700.5	31.13	720.8	32.03	620.5	27.57
2		28	685.4	30.4	761.3	33.83	805.2	35.78	901.1	40.04	742.5	33.0
3		56	843.0	37.46	893.2	39.69	982.3	43.65	1042	46.31	873.2	38.80

Table 4.3 Compressive strength (Water cement ratio - 0.45)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.45		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	528.0	23.4	609.6	27.09	642.2	28.54	685.0	30.44	598.8	26.61
2		28	667.0	29.6	710.2	31.56	761.6	33.84	873.0	38.8	714.2	31.74
3		56	820	36.4	847	37.64	942.7	41.89	999.6	44.42	835.3	37.12

It can be seen from the above outcomes that the compressive strength of the concrete increases by fusing cupola furnace slag up to 30% as a partial substitution to fine aggregates in all the mixes of concrete and then a decrease is observed in the strength of concrete on further addition of cupola slag to the concrete mix. The outcomes are plotted graphically for better understanding, for the curing time of 7, 28 and 56 days as shown in figures below.

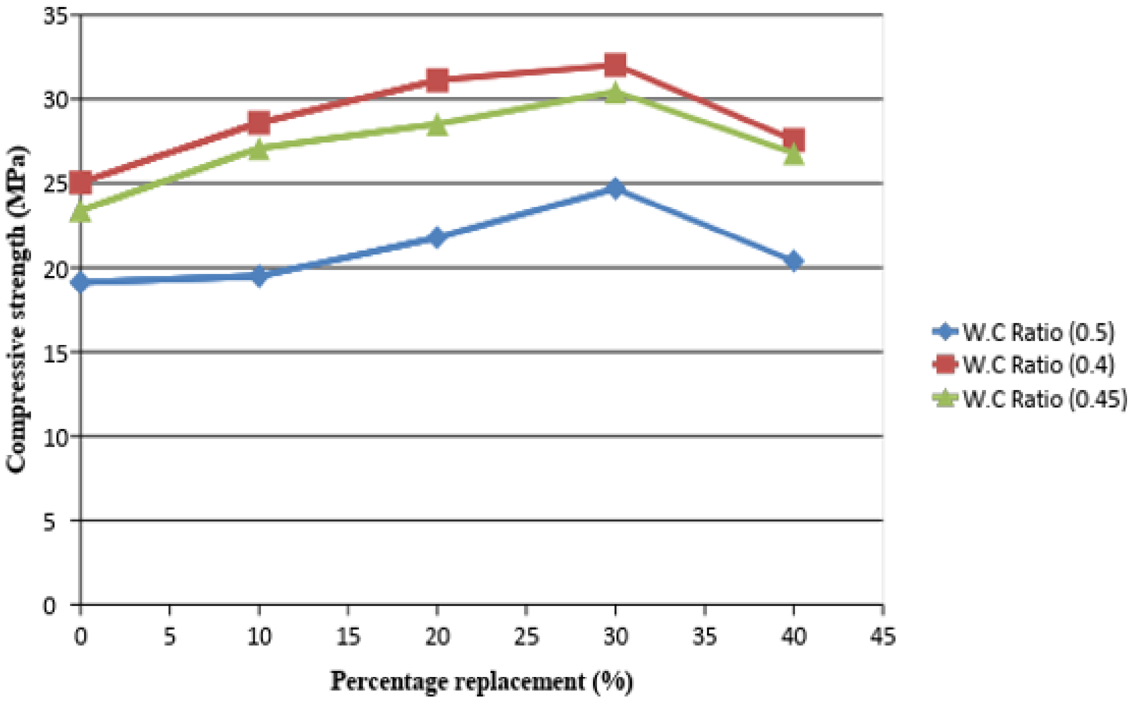


Fig. 4.1 Compressive strength of concrete at 7 days

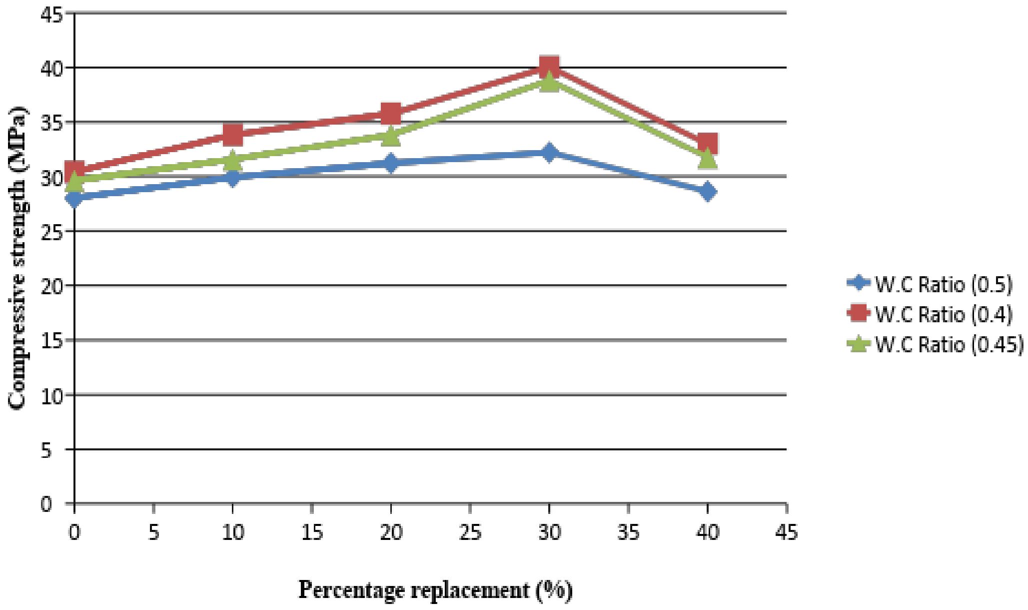


Fig. 4.2 Compressive strength of concrete at 28 days

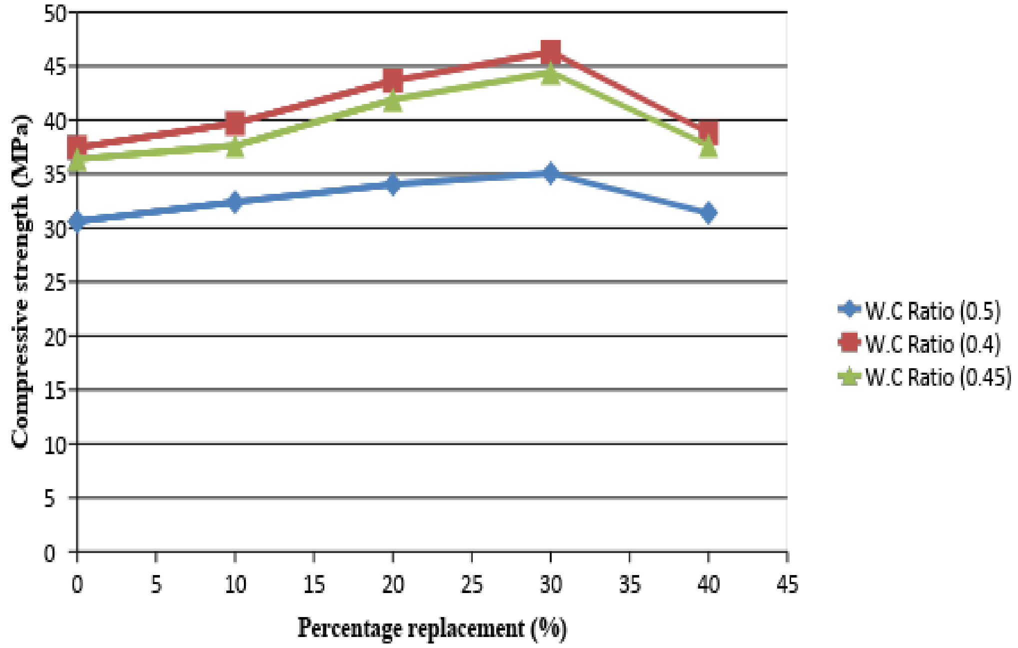


Fig. 4.3 Compressive strength of concrete at 56 days

The outcome shows that on replacement of fine aggregates by 10% of cupola slag shows an increase in the compressive strength of the concrete by 1.93%, 14.12% and 15.76% for w/c of 0.50, 0.40 and 0.45, after placing of cubes for a curing time of 7 days. So also, a substitution of 20% fine aggregates with cupola furnace slag, further shows an increase in compressive strength by 13.95%, 24.22% and 21.96% for w/c of 0.50, 0.40 and 0.45, separately. Besides, a substitution of 30% of fine aggregates with that of cupola slag prompts an expansion in compressive quality by 29.11%, 27.81%, 30.08% for w/c of 0.50, 0.40 and 0.45, separately subsequent to the curing time of 7 days and then there is a decrease at 40% replacement.

Additionally, for the 28 days curing period, a replacement of 10% of fine aggregates with that of cupola slag prompts increment in compressive strength by 6.78%, 11.28% and 6.62% for w/c of 0.50, 0.40 and 0.45, individually. Thus, further replacement of 20% fine aggregates with that of slag leads to increment in compressive strength by 11.42%, 17.69% and 14.32% for w/c of 0.50, 0.40 and 0.45 individually. Further, a substitution of 30% of fine aggregates with that of cupola furnace slag prompts increment in compressive strength by 15.0%, 31.71% and 31.08% for w/c of 0.50, 0.40 and 0.45, individually after completion of 28 days of curing period following an example fundamentally to the previous one curing time.

Additional to the above two, results obtained for the 56 days curing period shows that on substitution of 10% of fine aggregates with that of cupola furnace slag shows an increment in compressive strength by 5.88%, 5.95% and 3.40% for w/c of 0.50, 0.40 and 0.45, as a whole. Thus, further replacement of 20% fine aggregates with that of the cupola furnace slag shows an increment in compressive strength by 11.20%, 16.52% and 15.08% for w/c of 0.50, 0.40 and 0.45 respectively. Further, on substitution of 30% of fine aggregates with that of cupola furnace slag prompts increment in compressive strength of concrete by 14.60%, 23.62% and 22.03% for w/c of 0.50, 0.40 and 0.45, individually after completion of curing period of 56 days and on further substitution of fine aggregates with that of slag shows a decreasing trend and thus affecting strength as well.

Additionally, it can even be observed that the increment in the quality of the concrete in terms of compressive strength is higher at lower w/c ratios when calculated at different curing periods and with various percentage replacement of cupola slag, in this way demonstrating the reasonableness of utilization of cupola furnace slag where strength requirements are there. Moreover, in case of slag if atmospheric conditions are not harsh then we may observe more increase in the strength of concrete on substitution by slag. This increment observed in the strength may be occurring due to the transition zone or the inter facial zone which is being improved on addition of cupola slag to the concrete. The proper bondage of aggregates which is further enhanced by adding slag to it, as it is filling all the minute pores present in it as well and thus making it more compact. In this compressive strength is improved.

From the above observations it is clearly depicted that uptill 30% replacement of fine aggregate an increase in compressive strength is seen. Thus, from the observations it is clear that further increment in percentage of cupola slag beyond 30% leads to a decline in strength of the concrete. In this way, it can be inferred that the ideal rate level of substitution of fine aggregates with that of cupola furnace slag is 30% and it can be understood from the **Fig. 4.4, 4.5 and 4.6**.

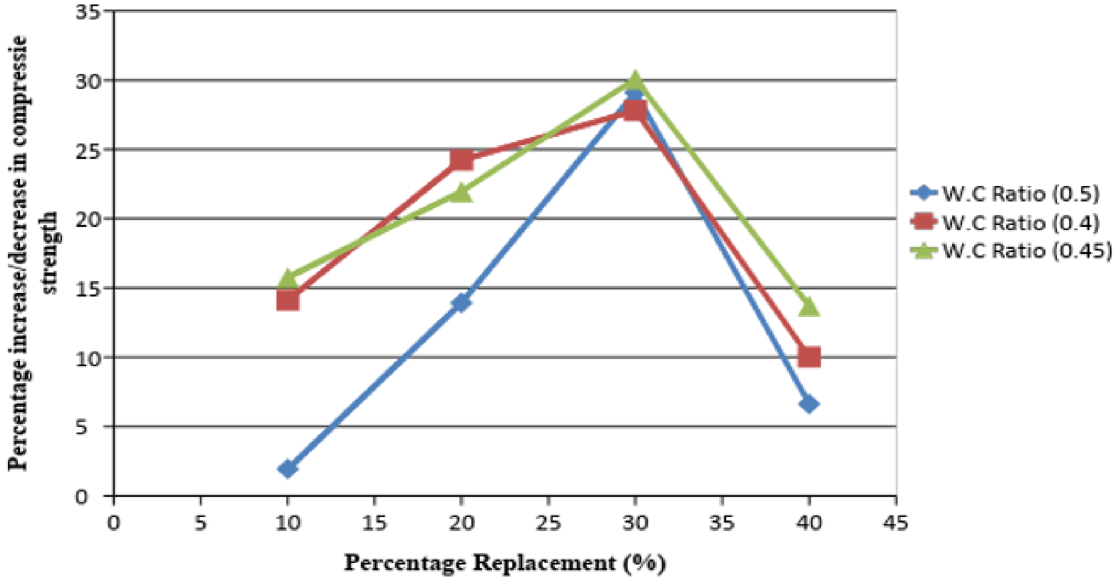


Fig. 4.4 Percentage increase/decrease in compressive strength for 7 days

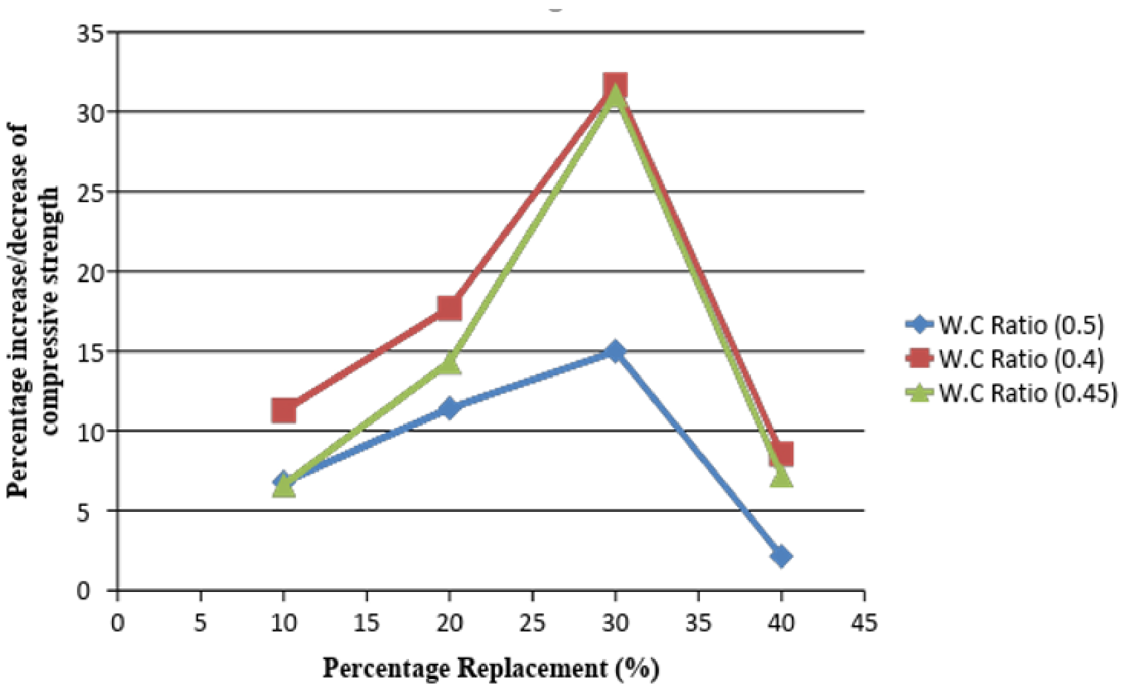


Fig. 4.5 Percentage increase/decrease in compressive strength for 28 days

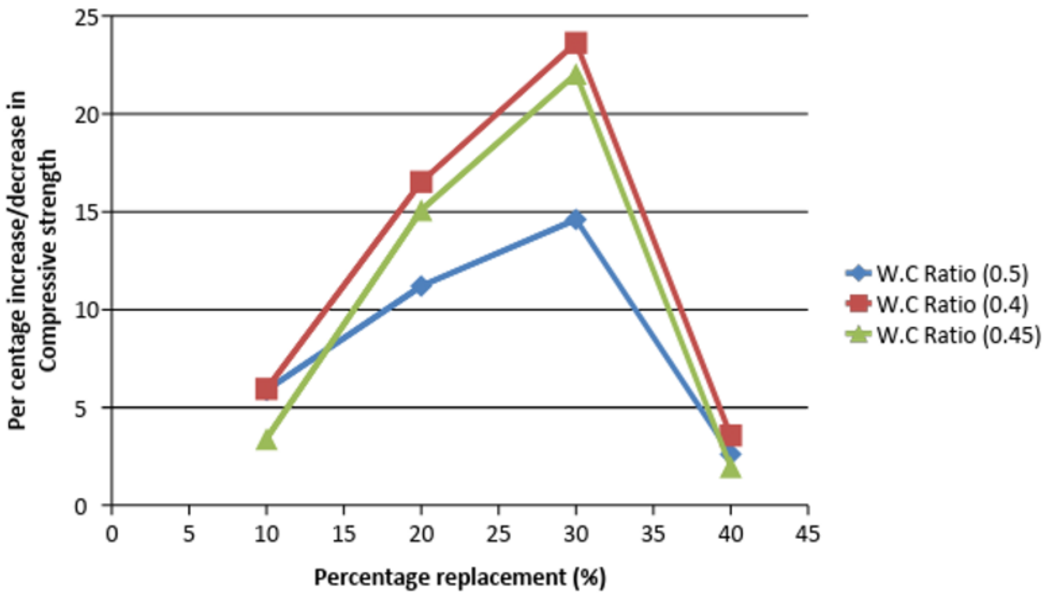


Fig. 4.6 Percentage increase/decrease in compressive strength for 56 days

4.3 SPLIT TENSILE STRENGTH

The testing of split tensile strength of concrete is usually done by casting of cylinders having dimensions of size 150mm x 300mm for various water cement ratio as 0.5, 0.4 and 0.45 for a curing time of 7, 28 and 56 days. The results which are observed for split tensile strength are shown in **Table 4.4, 4.5 and 4.6**.

Table 4.4 Split Tensile Strength Results of Cylindrical Specimen (W.C Ratio - 0.50)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.50		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	115.3	1.62	127.6	1.80	150.9	2.13	151.1	2.14	140.9	1.98
2		28	174	2.47	176.8	2.50	196.6	2.78	198.4	2.80	185.4	2.62
3		56	199.2	2.81	202	2.85	206.7	2.92	211.3	2.98	202.6	2.86

Table 4.5 Split Tensile Strength Results of Cylindrical Specimen (W.C Ratio - 0.40)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.40		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	170.3	2.40	185	2.61	208.7	2.95	221.6	3.13	178.4	2.52
2		28	192.3	2.72	210.5	2.97	235.2	3.32	250.8	3.54	205.6	2.90
3		56	207.2	2.93	225.9	3.19	240	3.39	265.4	3.75	218.6	3.09

Table 4.6 Split Tensile Strength Results of Cylindrical Specimen (W.C Ratio - 0.45)

S. No	W/c Ratio	Curing Period (days)	Normal Mix		Fine Aggregate replacement with cupola slag in steps of							
	0.45		Load (KN)	Stress (MPa)	10%		20%		30%		40%	
					Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)	Load (KN)	Stress (MPa)
1		7	161.4	2.28	168	2.37	193.4	2.73	198.4	2.80	188.1	2.66
2		28	174.4	2.46	182.2	2.57	205.2	2.90	223.2	3.15	190.5	2.69
3		56	182.6	2.58	191.3	2.70	212.7	3.0	230.4	3.25	193.6	2.73

It can be seen from the above outcomes that the split tensile strength of the specimens is showing an increase on partial substitution of cupola furnace slag with fine aggregates till 30% replacement only, generally applicable to all mixes of concrete. Further this value keeps on decreasing if any further increase in percentage replacement of slag is done in concrete. The outcomes are plotted graphically for better understanding of results obtained for the curing time of 7, 28 and 56 days.

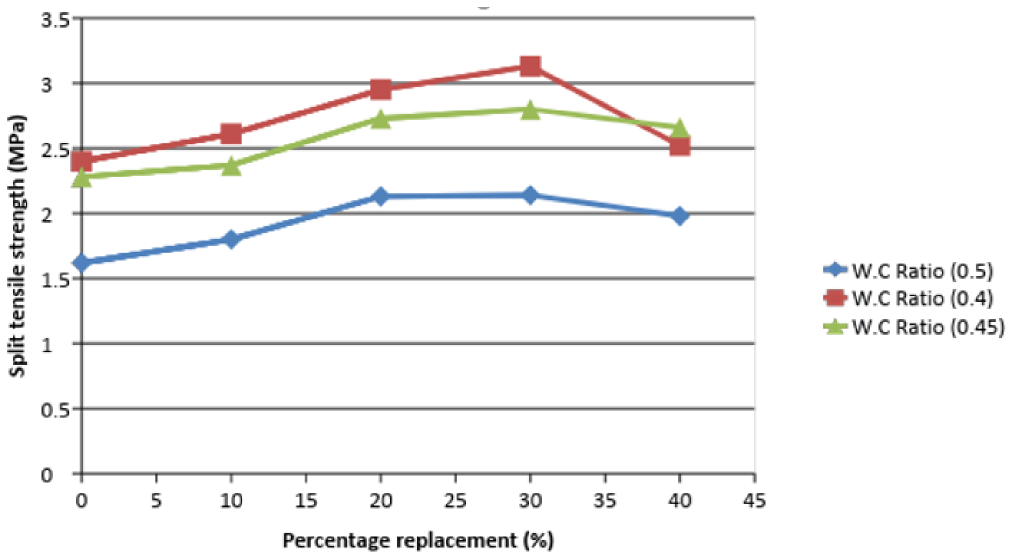


Fig. 4.7 Split tensile strength of concrete at 7 days

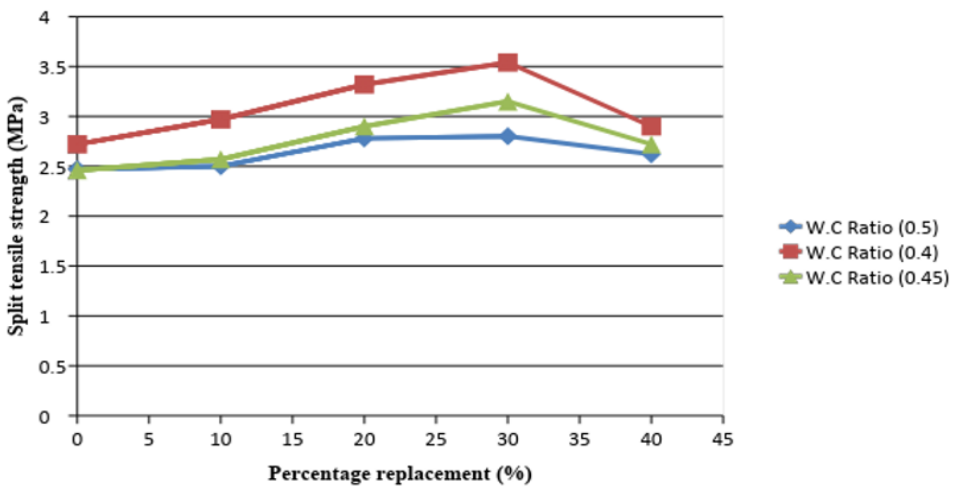


Fig. 4.8 Split tensile strength of concrete at 28 days

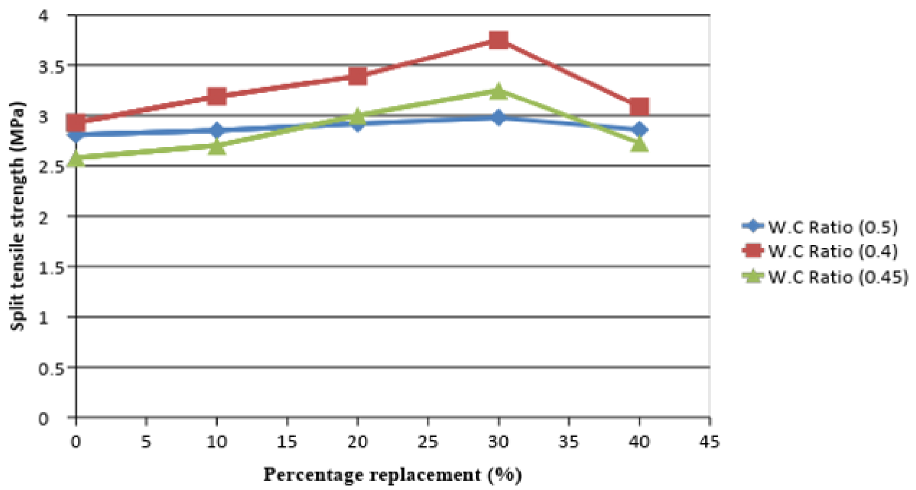


Fig. 4.9 Split tensile strength of concrete at 56 days

The outcomes obtained demonstrates that a substitution of 10% of fine aggregates with that of cupola furnace slag prompts an increment in split tensile strength by a measure of 11.11%, 8.75% and 3.94% for w/c of 0.50, 0.40 and 0.45 separately in the wake of curing time of 7 days. Thus, a replacement of 20% fine aggregates with that of cupola slag shows an increment in split tensile strength by 31.48%, 22.91% and 19.73% for w/c of 0.50, 0.40 and 0.45, individually. Further, with the substitution of 30% of fine aggregates with that of cupola furnace slag leads to an increment in split tensile strength by 32.09%, 30.41% and 22.8% for w/c of 0.50, 0.40 and 0.45 individually, for the curing time of 7 days and further a decrease is observed as appeared in **Fig. 4.10**. The pattern is almost fundamentally the same as we have observed for the results of compressive strength test.

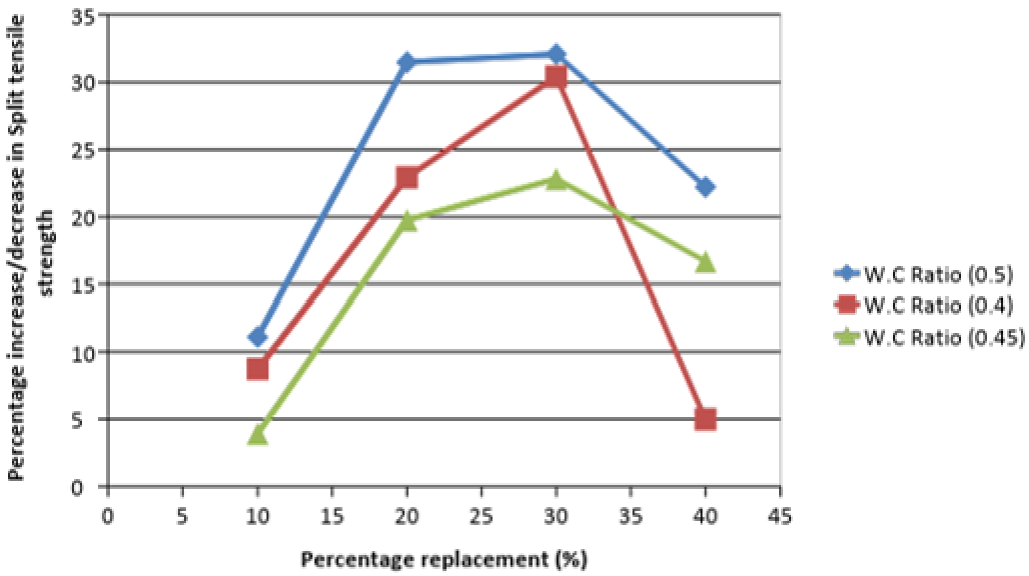


Fig. 4.10 Percentage increase/decrease in split tensile strength for 7 days

The substituting process of 10% of fine aggregates with that of the cupola slag basically shows an increasing trend in split tensile strength by 1.21%, 9.19% and 4.47% for w/c of 0.50, 0.40 and 0.45 individually subsequent to curing time of 28 days. Correspondingly, with the supplanting of 20% fine total with that of dome slag prompts increment in split tensile strength by 12.5%, 22.05% and 17.88% for w/c of 0.50, 0.40 and 0.45 individually. Further, with the substitution of 30% of fine total with that of dome slag prompts increment in split strength by 13.36%, 30.14% and 28.04% for w/c of 0.50, 0.40 and 0.45 individually in the wake of curing time of 28 days as appeared in **Fig. 4.11**.

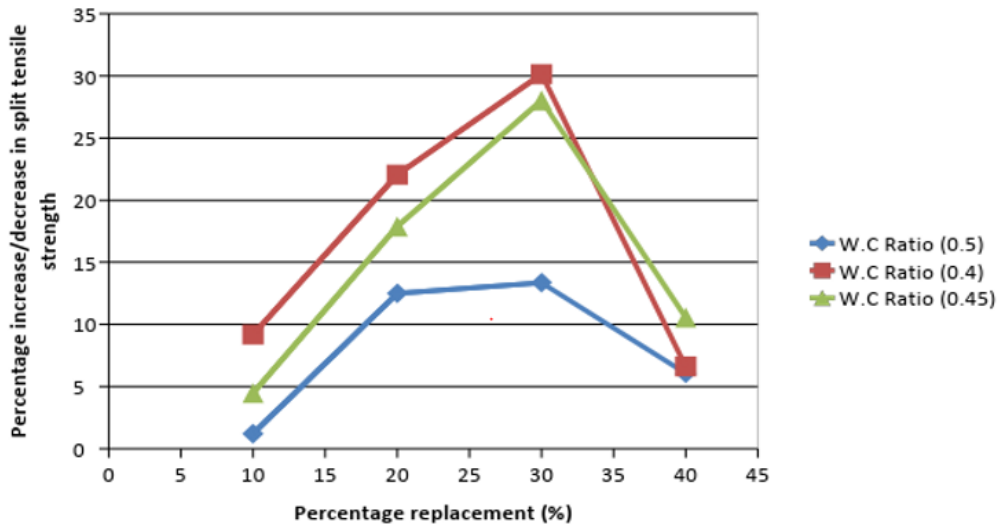


Fig. 4.11 Percentage increase/decrease in split tensile strength for 28 days

The outcomes we have obtained from the test carried out demonstrates that a substitution of 10% of fine aggregates with cupola furnace slag shows an increment in split tensile strength by a measure of 1.42%, 8.80% and 4.65% for w/c ratio of 0.50, 0.40 and 0.45 separately for the curing time of 56 days. Moreover, a replacement of 20% fine aggregates with that of cupola furnace slag shows an increment in case of split tensile strength by 3.91%, 15.67% and 16.27% for w/c ratio of 0.50, 0.40 and 0.45, individually. Thus, with the replacement of 30% of fine aggregates with that of cupola slag further leads to an increment in strength of split tensile by 6.04%, 27.98% and 25.96% for w/c ratio2of 0.50, 0.40 and 0.45 distinctly, for the curing period of 56 days and after that a decrease is seen as appeared in **Fig. 4.12**.

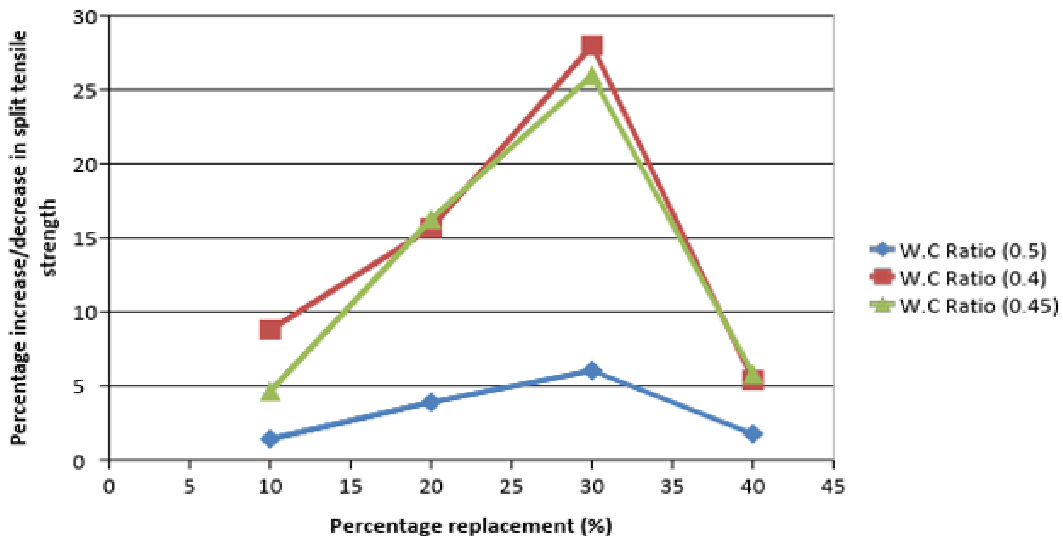


Fig. 4.12 Percentage increase/decrease in split tensile strength for 56 days

It can be additionally seen, that when we compare in terms of compressive strength and split tensile strength then we will observe, that the rate increment in case of compressive strength is slightly higher at lower w/c ratios for different curing periods, in this manner demonstrating the reasonableness of utilization of cupola furnace slag where strength requirement is slightly more than the normal ones. This increment can be ascribed to the way that the transition zone between the aggregates is enhanced due the usage of cupola slag, consequently increasing the compressive strength and to some extent split tensile strength as well.

It can likewise be observed that a further increment in level of cupola furnace slag past 30% brings about a decrease in the strength in both compressive and split tensile strength. Along with these, it can be concluded that the ideal rate level of substituting of fine aggregates with cupola slag is 30% as beyond it decrease is observed.

4.4 WATER PERMEABILITY TEST

In this test we will be observing the variation seen on replacement of fine aggregates with that of cupola furnace slag. Firstly, we will vary the percentage of replacement from controlled concrete uptill 40% at a particular water cement ratio. For conducting this test three w.c ratios were considered (0.4, 0.45 and 0.5) and further replacement was carried out for each w.c ratio separately. At last noting down the values observed and drawing conclusions from it.

Table 4.7 Water Permeability Test (w.c ratio – 0.5)

Sr. No.	Percentage replacement (%)	Water penetration depth (cm)	
		28 days	56 days
1.	C.C	1.9	1.71
2.	10%	1.8	1.54
3.	20%	1.6	1.4
4.	30%	1.3	1.2
5.	40%	1.1	1.0

Table 4.8 Water Permeability Test (w.c ratio – 0.4)

Sr. No.	Percentage replacement (%)	Water penetration depth (cm)	
		28 days	56 days
1.	C.C	1.5	1.25
2.	10%	1.3	1.13
3.	20%	1.1	0.82
4.	30%	0.9	0.6
5.	40%	0.7	0.54

Table 4.9 Water Permeability Test (w.c ratio – 0.45)

Sr. No.	Percentage replacement (%)	Water penetration depth (cm)	
		28 days	56 days
1.	C.C	1.6	1.50
2.	10%	1.45	1.34
3.	20%	1.2	1.15
4.	30%	1.0	0.83
5.	40%	0.9	0.61

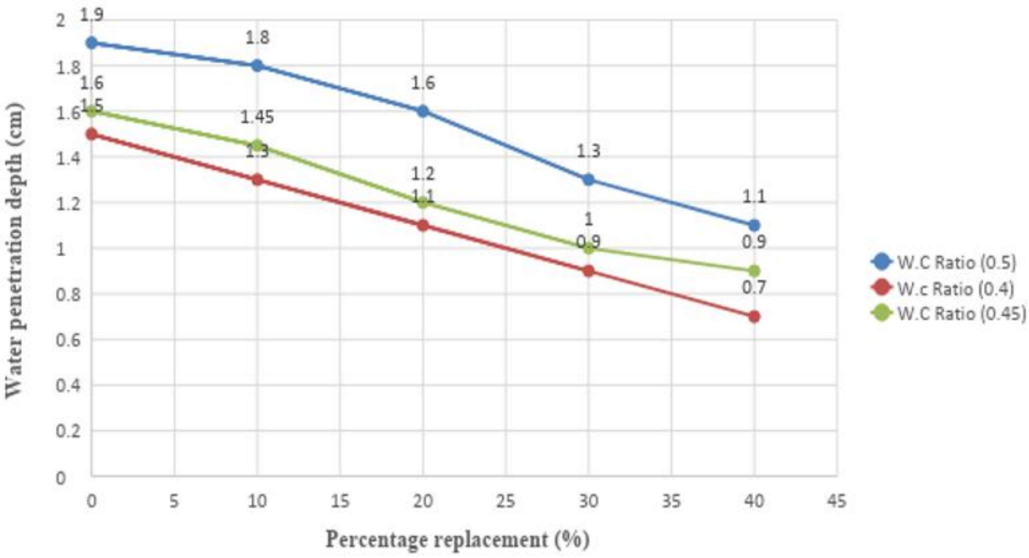


Fig. 4.13 Water permeability of concrete at 28 days

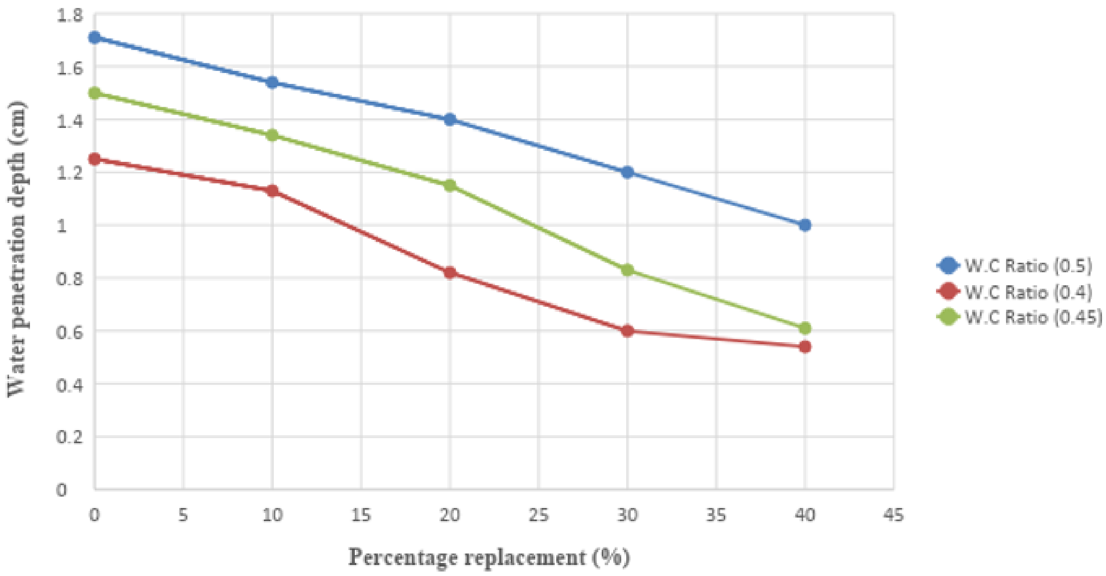


Fig. 4.14 Water permeability of concrete at 56 days

It can be clearly seen from the graphs drawn that on replacement of fine aggregates with that of cupola furnace slag ranging from 0% to 40% shows that there is decrease in the water penetration depth of the concrete mix when observed at 28 days. This decrease is most prominent at the w.c ratio 0.4 as can be clearly seen from the graph itself. Further, apart from the above information we will even observe that the difference between the values of water penetration depth is less in case of w.c ratio 0.4 and 0.45 on comparison with 0.5.

Similarly, it can be seen that on replacing fine aggregates with that of cupola furnace slag varying from 0% till 40% shows that there is decrease observed in the water permeability or water penetration depth of the concrete mix when observed at 56 days of curing period. This decrease can be clearly seen at the w.c ratio 0.4 instead of other ratios. Further, above this the additional information which can be provided is that the difference between the values obtained for water penetration depth is less in case of w.c ratios 0.4 and 0.45 on comparing it with 0.5. Moreover, the gap observed in the graph is quite prominent because of the difference in the values.

4.5 ABRASION RESISTANCE

While carrying out abrasion resistance test, the first and the foremost thing is to calculate mass loss in specimens and along with this, loss in thickness is even observed. Further substituting cupola furnace slag with fine aggregates in various proportions. The variation of slag is kept between 0% to

40%. Similarly following all same steps, test is conducted on different w.c ratios i.e. 0.4, 0.45 and 0.5 and keeping the replacement parameters same.

Table 4.10 i) Abrasion test (w.c ratio – 0.5) (28 days)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm)
1.	0	235.42	233.57	1.85	0.212
2.	10	237.12	235.39	1.73	0.205
3.	20	239.31	237.79	1.52	0.182
4.	30	241.5	240.19	1.31	0.164
5.	40	243.17	241.93	1.24	0.143

ii) Abrasion test (w.c ratio– 0.4)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm)
1.	0	224.13	222.78	1.35	0.141
2.	10	226.34	225.05	1.29	0.120
3.	20	229.5	228.27	1.23	0.108
4.	30	231.0	229.82	1.18	0.101
5.	40	232.71	231.62	1.09	0.09

iii) Abrasion test (w.c ratio – 0.45)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm)
1.	0	229.4	227.83	1.57	0.173
2.	10	230.7	229.28	1.42	0.154
3.	20	233.15	231.88	1.27	0.139
4.	30	236.8	235.65	1.15	0.117
5.	40	239.42	238.3	1.12	0.109

Table 4.11 i) Abrasion test (w.c ratio– 0.5) (56 days)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm)
1.	0	232.17	230.34	1.83	0.198
2.	10	236.46	234.75	1.71	0.176
3.	20	238.13	236.64	1.49	0.151
4.	30	240.75	239.47	1.28	0.134
5.	40	242.6	241.39	1.21	0.115

ii) Abrasion test (w.c ratio – 0.4)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm)
1.	0	221.42	220.11	1.31	0.134
2.	10	223.51	222.24	1.27	0.118
3.	20	227.12	225.91	1.21	0.103
4.	30	229.6	228.45	1.15	0.07
5.	40	231.75	230.68	1.07	0.05

iii) Abrasion test (w.c ratio – 0.45)

Sr. No.	Percentage replacement (%)	Initial mass (g)	Final mass (g)	Δm (Mass loss, g)	Δt (Thickness loss, mm^3)
1.	0	224.7	223.17	1.53	0.157
2.	10	228.19	226.8	1.39	0.143
3.	20	232.72	231.48	1.24	0.127
4.	30	235.1	233.99	1.11	0.113
5.	40	238.24	237.16	1.08	0.102

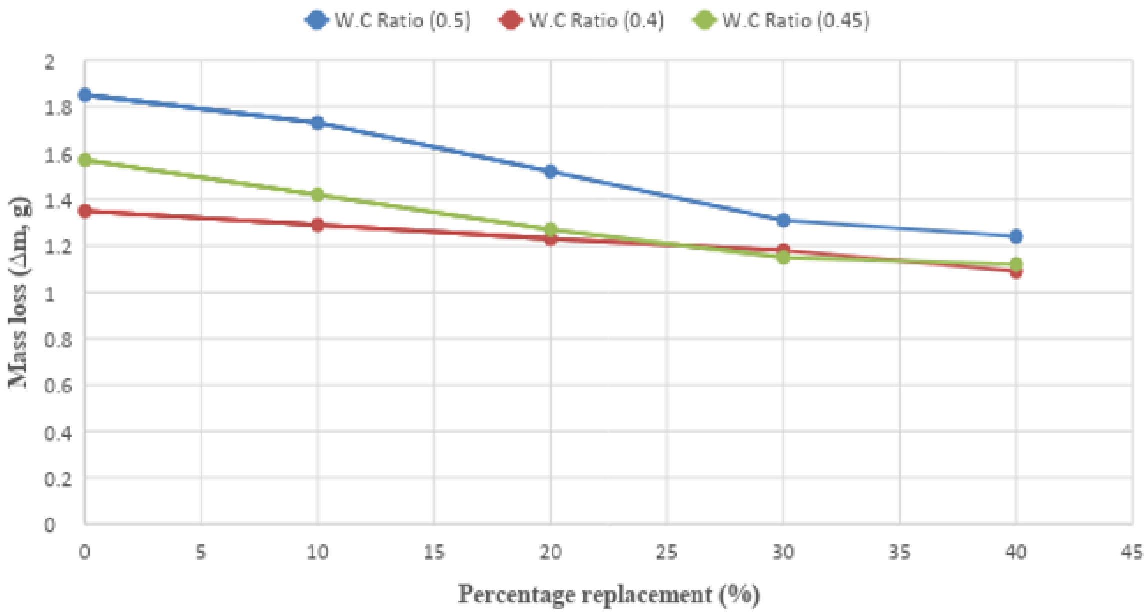


Fig. 4.15 Abrasion resistance of concrete at 28 days

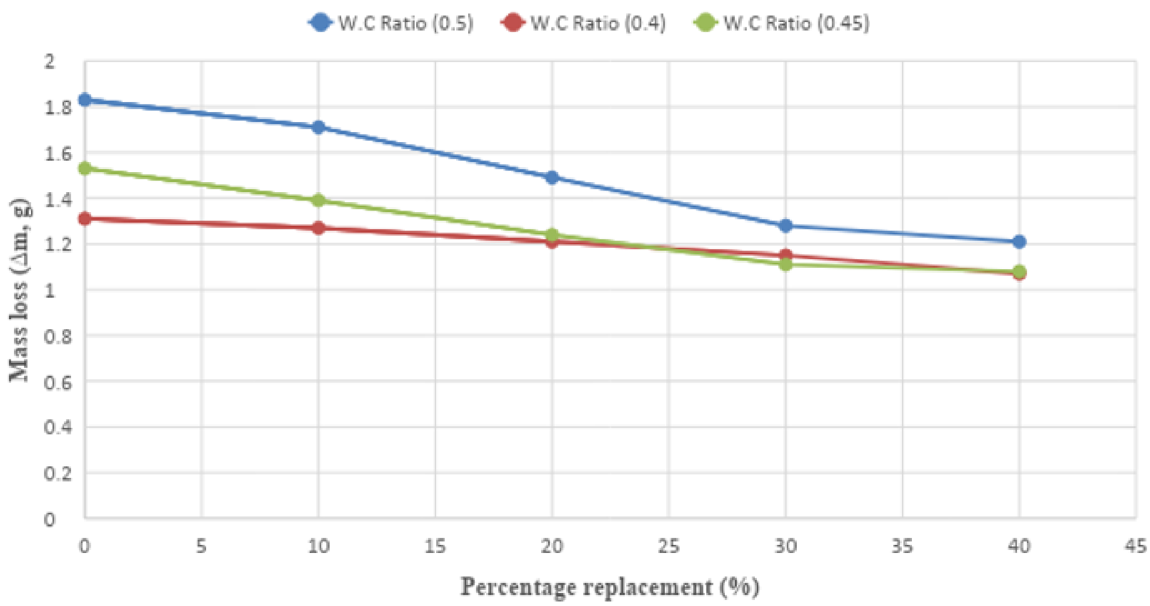


Fig. 4.16 Abrasion resistance of concrete at 56 days

For better understanding of results, it is always better to plot them graphically for visualization purpose. It can easily be interpreted from the graphs drawn that as we keep on increasing the percentage of replacement of cupola slag from 0% to 40% with fine aggregates decrease in abrasive nature of concrete is observed. Along with this the decrease in abrasive nature is even observed on decreasing w.c ratio from 0.5, 0.45 to 0.4 for 28 days of curing period. In the graph the values for w.c ratio 0.4 and 0.45 seems to be almost same or somewhere close but still 0.4 w.c ratio has given us better results.

On the similar pattern when we replace fine aggregates with that of cupola furnace slag it shows us almost same trend i.e. decrease in abrasive resistance of the concrete mix for the curing period of 56 days. Variation of slag is kept till 40% only in order to observe changes which concrete undergoes for the same parameter at different curing period and along with this varying w.c ratio as well. Out of all the three w.c ratios tested 0.4 is the one which is showing better results in comparison to the other ratios.

CHAPTER 5

CONCLUSION

5.1 GENERAL

Keeping in mind the end goal to accomplish from the present examination, a trial was carried out following all experimental procedure in order to obtain results obtained for various parameters such as Compressive strength, split tensile strength, water permeability test and Abrasion resistance test by casting of various concrete specimens using cupola furnace slag as a replacement to fine aggregates. Various tests conducted in this study is basically carried out by varying cupola slag from 0% to 40% as a substitution and thus observing trends in various parameters. Thus, following conclusions are drawn from the study.

5.2 COMPRESSIVE STRENGTH

- Increase in compressive strength is observed uptill 30% replacement of fine aggregates with cupola furnace slag.
- The major increase in compressive strength of concrete is seen at lower water cement ratios i.e. out of 0.4, 0.45 and 0.5 best results were observed at 0.4 water cement ratio.
- From the analysis of the results it is quite prominent that the increase in compressive strength is observed till 30% replacement only and after this percentage a decrease is observed. Thus making 30% as an optimum substitution percentage for strength.
- As this test is being carried out for curing period of 7, 28 and 56 days and thus at these curing days it is observed that sudden increase is observed in initial phase i.e. 7 days as compared to the other days.

5.3 SPLIT TENSILE STRENGTH

- Increase in split tensile strength is observed till 30% replacement of fine aggregates with cupola furnace slag.
- In case of split tensile strength increase is observed in case when we move from higher water cement ratio to lower ones as it is helping in strength gaining.

- Moreover, similar trend is seen as in case of compressive strength, as the optimum percentage replacement ratio is 30% only and beyond this percentage decrease starts.
- Generally tensile strength of concrete is less thus it even helps in enhancing it to a particular level so that fields of usage of concrete can be widen up.

5.4 WATER PERMEABILITY

- The water permeability of concrete decreases on partial replacement of fine aggregates with cupola slag till 40%.
- Same case is seen in case of water permeability as well that on lowering water cement ratio better resistance to water penetration is observed.
- On observing the values obtained at various percentage replacement we can conclude that on increasing percentage replacement decreasing trend is seen. Thus because of continuous decrease no optimum ratio is decided.
- This replacement helps in making concrete more non-porous and further preventing reinforcement from various environmental impacts and 0.4 is the most suitable ratio for it.

5.5 ABRASION RESISTANCE

- This test is carried out in order to check abrasive resistance of the concrete thus preventing it from wear and tear on partial replacement by slag.
- The increase in abrasiveness of concrete is shown towards lowering of water cement ratios and results at 0.4 water cement ratio are better than the rest.
- As such no ratio is optimized because of continuous decreasing trend in the abrasive resistance on increasing percentage replacement from 0% to 40%.
- This parameter is important because of the fact that concrete is even used in the pavements thus we need to minimize the abrasion within concrete for more durability.

5.6 SCOPE FOR FUTURE WORK

- In this study, effect on replacement of fine aggregates with that of cupola furnace slag is analyzed in terms of Compressive strength, split tensile strength, Water permeability and Abrasion resistance test. It can further be extended to other properties as well.

- In case of Water permeability and Abrasion resistance study is just done till 40% replacement only but it should be extended to higher replacement as well in order to find optimum percentage.
- Moreover, effect on fine aggregates is only observed i.e. basically sand only. It will be better if cupola slag can be used for replacement of cement as well as it will help in making construction much more economical.

REFERENCES

1. A. Andrews, E. Gikunoo, L.Ofosu- Mensah, H. Tofah, S. Bansah "Chemical and Mineralogical Characterization of Ghanian Foundry Slags", Journal of Minerals and Materials Characterization & Engineering, Vol 11, No.2.2012. Page 183-192
2. Chinwuba Arum and Grace Oluwaseun Mark "Partial Replacement of Portland Cement by Granulated Cupola Slag- Sustainable Option for Concrete of Low Permeability", Civil and Environmental Research, Vol o. No.3,2014, Page 17-26.
3. D. Baricova A. Pribulova, P. Demeter "Comparison of possibilities the blast furnace and cupola slag utilization by concrete production", Archives of Foundry Engineering Vol 10,Special Issues 2/2010, Page 15-18.
4. Donald W. Lewis March "Durability of slag cement concretes"- National slag association, NSA 181-3, Suite 2, 110 W. Lanchester Avenue, Wayne, PA, 1981.
5. Donaid W. Lewis "History of stag cements"- National slag association, MF 181-6, Suite 2, 110 W. Lanchester Avenue, Wayne, PA. 1981.
6. Environmental Technology Best Practice Programme "Savings from re-use of a foundry by-product"- A case history from Triplex Williams Ltd. and Potterton Myson Ltd, 1999.
7. Gopal Charan Behera, Monika Mohanty, Sudeep Rohan Bagh, Indummathab Sarkar, Satyajit Singh "Slag as Coarse Aggregate and Its Effect on Mechanical Properties of Concrete", International journal of Earth Sciences and Engineering, Vol. 04, No. 06, 2011, Page 899-902.
8. John Zachar and Tarun R. Naik "More Sustainable and Economical Concrete Using Fly Ash, Used Foundry Sand, and Other Residuals", The University of Wisconsin Milwaukee centre for By-products Utilization, Second International conference on Sustainable construction Materials and Technologies, 2010
9. Joseph O. Afolayan and Stephan A. Alabi "investigation on the Potentials of Cupola Furnace Slag in Concrete", International journal of Integrated Engineering, Vol. 5 No. 2, 2013, Page 59-62.

10. Li Yun-feng Yao Yan, Wang Ling "Recycling of industrial waste and performance of steel slag green concrete", Journal of Central South University of Technology, China, Vol 16, No. 5, 2009, Page 768-773.
11. L Zeghichi "The effect of replacement of naturals aggregates by slag products on the strength of concrete. Asian journal of Civil Engineering (Building and Housing) Vol 7, No.1, 2006, Page 27-35.
12. M.H. Joulazadeh, F. Joulazadeh "Slag- Value added Steel industry by products", Archives of metallurgy and materials, Vol 55, No. 4, 2010, Page 1137-1145.
13. M.L. Gambhir "Concrete Manual-A Laboratory manual for quality control of concrete" Dhanpat Rai and Sons, Delhi, 1992.
14. Mohammed Nadeem, Arun D. Pofale "Utilization of Industrial Waste Slag as Aggregate in Concrete Applications by Adopting Taguchi's Approach for Optimization". Open Journal of Civil Engineering, Vol. 2, No. 3,2012, Page 96-105.
15. National slag association "Blast furnace slag as an Agricultural liming material and source of minor plant nutrients"- MF 181-5, Suite 2,110 W. Lanchester Avenue, Wayne, PA.
16. National slag association "Blast furnace slag slurry seals"- NSA 175-3, Suite 2, 110 W.Lanchester Avenue, Wayne, PA
17. National slag association "Slag roofs", Suite 2, 110 W. Lanchester Avenue, Wayne, PA.
18. Public Works Research Institute "Technical Manual for the Use of Recycled Materials Generated by Other Industries in Construction Projects", Japan, 2005.
19. Raju, K.V.S. B, Pal, Ganesh M. Murthy, Neha, Anirudha, KV. Rao, P. Raghavendra "Geotechnical Characterization of Miscellaneous Wastes", Indian Geotechinica Conference, 2010.
20. RT. jones "Economic and environmentally beneficial treatment of slags in DC arc furnaces" VII International Conference on Molten Slags, Fluxes and Salts, The South African Institute of Mining and Metallurgy, 2004.

21. Saad Moghazy Salman, Hussein Darwish “Development of low cost glass-ceramic based on blast furnace slag and granite rock” - Glass Research Dept, National Research Centre, El-Behoos St., Dokki, Cairo, Egypt, 2005.
22. Sanjay Kumar, Rakesh Kumar, Amitava Bandopadhyay "Innovative methodologies for the utilization of wastes from metallurgical and allied industries”- Resources, Conservation and Recycling 48, 2006, Page 301-314.
23. S. Katz, “Slags’ Effects on Cast Iron Production" -American Foundry Society, 2004.
24. Sreekrishnaperumal Thanga Ramesh, Rajan Gandhimathi, Puthiya Veetil Nidheesh, Shanmuugam Rajakumar and Subramani Prateepkumar "Use of furnace slag and welding slag as replacement for sand in concrete”, International journal of Energy and Environmental Engineering, Vol. 4, No. 1,2013.
25. Tarun R. Naik, "Greener concrete using recycled materials"- Concrete International Magazine, Vol 24, No. 7,2002 Page 49-53.