UTILIZATION OF CUPOLA FURNACE SLAG AS PARTIAL REPLACEMENT TO COARSE AGGREGATES IN CONCRETE MIX

A dissertation submitted in partial fulfillment for the requirement of degree of

Master of Engineering
in
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By

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CERTIFICATE

This is to certify that the thesis entitled "**Utilization of Cupola Furnace Slag as Partial Replacement to Coarse Aggregates in Concrete Mix**" is an authentic record of my own work carried out as per requirements for the award of degree of Master of Engineering in CAD/CAM & Robotics from Thapar University, Patiala, under the guidance of Dr. Maneek Kumar, (Professor, CED) and Dr. Jaswinder Singh Saini (Assistant Professor, MED) during the period July 2013 to July 2014.

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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 availability of good quality aggregates is 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 coarse aggregates in the concrete mix and to study the effect on compressive and split tensile strength 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 coarse aggregate.

The results show that the compressive strength as well as the split tensile strength of the concrete is increased by partial replacement of coarse aggregate up to 30% with cupola furnace slag. The percentage increase in the strength values is higher for higher water-cement ratios indicating its suitability for use in concrete mixes where strength requirements are low for all curing ages. Highest increase in strength values, both compressive as well as split tensile, is achieved for a 30% replacement of coarse aggregates with cupola furnace slag, indicating that 30% cupola slag is the optimum replacement percentage of coarse aggregates in the concrete mixtures.

The compressive and tensile strength of the concrete decreases beyond 30% replacement of coarse aggregate with cupola slag.

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CHAPTER-1

INTRODUCTION

1.0 GENERAL

There are around 6000 Cupola furnaces installed in India, out of which 1000 Cupola furnaces are installed in the state of Punjab only. Since the first cupola patent was taken out in England in the late eighteenth century; the furnace has remained the pre-dominant melting unit in iron foundries. Over the two intervening centuries, the basic operations of coke fired cupola have remained relatively unchanged, although the understanding of the process involved has improved considerably. The major clusters of Cupola furnaces in the state of Punjab are Ludhiana, Batala, Amritsar, Jalandhar, Mandi-Gobindgarh, Goraya, and Phagwara. Most of the cupola furnaces are of conventional design which produces a huge amount of slag due to the impurities present in the raw material. The problem of slag disposal is increasing day-by-day due to the decreased availability of free land which is creating a serious problem for the foundry industries.

Concrete is a widely used construction material in the construction industry worldwide. The use of cementitious material can be traced back thousands of years ago to Italy, Greece, ancient Egypt and the Middle East. Portland cement, an important ingredient in modern concrete was first used in 1824 by Joseph Aspdin in England and the production of Portland cement in the modern sense began about 20 years later by Isaac C. Johnson. Since ancient time, mankind has been searching for construction materials with higher and higher performance to build taller, longer and sounder structures. As the cost of concrete construction materials like cement escalates and natural aggregate resources begin to increase, demand has risen for use of alternative materials as full or partial replacement of cement as well as aggregates.

Cupola furnace slag, being a waste material, a by-product of an industrial process is available in abundance in the region. Its use as an alternative to the coarse aggregate in concrete is a worthwhile investigative issue. Its use will help utilizing one more waste product, many of which are lying abandoned and un-utilized occupying large amounts of useful spaces in the country.

1.1 WORKING PRINCIPLE OF CUPOLA FURNACE

The cupola furnace is a vertical shaft furnace operating on the counter current principle, shown in Fig 1.1. Cold charge materials are fed into the top of the unit and are pre heated by the products of combustion of coke as they descend and melt before being tapped out near the base. A coke bed is established at the bottom of the cupola furnace. Blast air is provided by a FD fan which provides the air in wind box and the air gets distributed uniformly in the cupola from wind box with the help of tuyeres. The cupola furnace is not a dead melting furnace in which the melting process is accompany by a number of compositional charges. The cupola is refractory lined and as the melting campaign proceeds, the refractory is mechanically and chemically eroded until the remaining thickness is insufficient to allow for continued safe operation. The eroded lining material together with coke ash, dirt from the charge materials and appropriate fluxes usually limestone results in the formation of slag which is removed by slag hole. Pick up of carbon in cupola depends on the various factors such as initial carbon content of the charge mixture, the amount and quality of coke, coke bed temperature, cupola well depth and metal tapping temperature etc.

Fig.1.1 Cupola furnace

1.2 AMOUNT OF SLAG GENERATED

In the cupola furnace, for every production of 1Ton of molten metal, 50 kg of slag is produced approximately *i.e.* 5% of the molten metal produced. The pictorial view of slag formation is shown in Fig. 1.2.

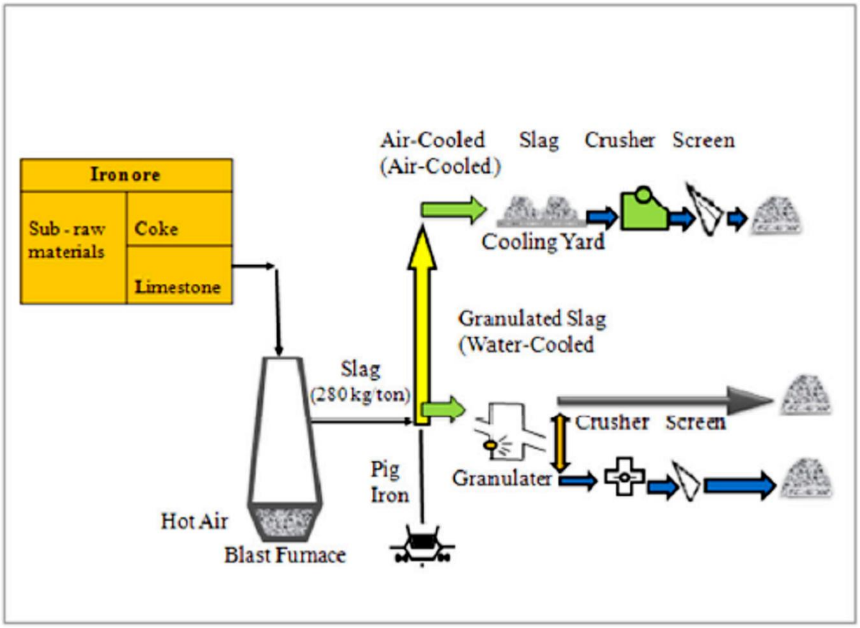


Fig. 1.2 Blast furnace operation and slag production

In general, the cupola operates for the duration of 7-8 hrs/heat producing 20-25T of molten metal/heat depending on the size of cupola furnace. 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 quantum of slag generated is very large with negligible productive utilization in any of the manufacturing process. It is used only for the purpose of land filling that too with the financial burden on the industrialists for the slag clearance.

1.3 NEED TO UTILIZE CUPOLA SLAG

In this universe, each and every personnel requires his basic needs i.e. food, cloth and shelter. As far as shelter is concerned, one thinks that his shelter should be unique. The nature is unable to provide the raw material to human beings to fulfill the desire of making a shelter due to the uncontrollable growth of population. A human being is always innovative in his ways and means to fulfill his desires. The scarcity of the natural aggregate, used in concrete, has compelled many researcher to think about the replacement options. Now-a-days, the emphasis is on the avoidance of waste generation, recycling and reuse of waste, and minimizing the adverse impact of 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 availability of good quality aggregates is depleting day by day due to tremendous growth in Indian construction industry.

Aggregates are the main ingredient of concrete occupying approximately 75% of its volume and directly affecting the fresh & hardened properties. Concrete being the largest man made material used on earth is continuously requiring good quality of aggregates in large volumes. A need was felt to identify potential alternative source of aggregate to fulfill the future growth aspiration of Indian construction industry. Use of slag as aggregates provides great opportunity to utilize this waste material as an alternative to normally available aggregates. The proper use of waste materials fundamentally affects our economy and environment. Over a period of time, waste management has become one of the most complex and challenging problems in India affecting the environment. The waste byproducts are generated which are environmentally hazard and create problems of storage due to rapid growth of industrialization. The construction industry has always been at forefront in consuming these waste products. The consumption of slag, which is waste generated by foundry industry, in concrete not only helps in reducing green house gases but also helps in making environmental friendly material. Slag is a nonmetallic inert by-product primarily consisting of silicates, alumina silicates, and calcium-alumina-silicates.

1.4 STRUCTURE OF SLAG

Cupola slag tends to be dense, solid, vitrified material that varies in colour from cream to black, but the predominant colouration would be green to brown. Light coloured slag is sometimes associated with high basicity materials and darker slag with more oxidizing conditions in the furnace (Fig. 1.3).

Fig. 1.3 Slag Structure

If the iron content is too high and the lime level too low, the slag converts to Aero-chocolate appearance instead of being solid. Some slags will exhibit light coloured grains in their makeup which are usually refractory particles eroded from the furnace lining. The physical condition of the slag is also influenced by the collection practice followed. Conventional cold blast cupolas are usually operated such that any slag produced is tapped from the furnace either into slag bogeys or into pits in the floor of the foundry. In either case the slag solidifies in relatively large pieces subsequently it may break down into various sized lumps. Alternatively, some large furnaces operate with a wet slag granulation system where the slag exiting the furnace tapping/slagging box is broken up by a water stream. The slag resulting from this type of operation is relatively fine compared with slag pieces produced by conventional slagging practice.

1.5 PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF SLAG

The physical properties and chemical composition of the slag produced during the cupola operation are as given in Table 1.1

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

Sr. no.	Parameters	Value
Physical Properties		
1.	Specific Gravity	3.5
2.	Impact Value	6.1%
3.	Crushing Strength	35.5%
4.	Water absorption	0.4%
Chemical Composition		
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.	

1.6 PROBLEMS DUE TO SLAG FORMATION

1.6.1 Alloy Loss

When iron oxide slag come into contact with liquid cast iron, the elements like carbon, silicon and manganese are oxidized into their respective oxide. In effect, iron oxide converts expensive alloy materials into worthless oxides.

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

$$FeO_{slag} + S_{iron} = ½\ SiO_{2slag} + Fe \quad \textbf{.....(1.2)}$$

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

Although, MnO is a product of FeO oxidation, it in turn can oxidize silicon and carbon and can create many of the kind of problems as in the case of iron oxide.

1.6.2 Desulphurization

Desulphurization of liquid iron can be carried out in the cupola or in a ladle. It is well recognized that the level of CaO in the slag, usually expressed as basicity, is an important controlling factor. However, the level of MnO in the slag plays an equally important role. The higher the MnO level, the poorer the desulphurization. The presence of liquid slag entering with the iron stream or produced by oxidation in the ladle can seriously reduce the ability to desulphurize.

1.6.3 Refractory Problems

The inner surface of the cupola furnace is lined with refractory material which is susceptible to erosion by slag. The slag can combine with refractory material to form accretions that hamper production. The consequences of refractory problems are loss of production and the cost to replace the eroded refractory.

1.6.4 Casting Defects

The slag entering the mould can produce inclusion defects. Inclusions of iron-oxide rich slag create porosity by reaction with carbon to form Carbon monoxide. Iron oxide rich slag can also inhibit proper nucleation of graphite by oxidizing the inoculants.

1.7 THRUST AREAS FOR UTILIZATION OF SLAG

The cupola slag can be utilized in a number of applications, which may include:

- Replacement to natural coarse aggregate in concrete mix.
- Road building material.
- Agricultural liming material.
- Roofing granules.
- Production of blended cement.
- Anti skid material.
- Mineral wool for insulation purpose.
- Soil conditioner.

The merits of slag utilization are many fold and are enumerated as below:

- It has excellent bonding.
- It has greater insulation.
- It is light in weight.
- It helps in reducing the overall cost.
- It has higher fire resistance.

1.8 SCOPE OF THE PRESENT STUDY:

In the work carried out and presented herein, an effort has been made to study the variation in strength properties of concrete produced with cupola furnace slag as one of its ingredients. The slag, procured from the foundry industries of the Punjab region, has been used as partial replacement of coarse aggregates in the study.

LITERATURE REVIEW

2.0 GENERAL

A large number of researchers have shown interest in the utilization of various types of industrial slags in different constructive ways which include using it as a replacement material in concrete mixes, in cement production, as an insulation material, as a soil conditioner etc. The different approaches followed by various researchers in utilization of slag in different fields has been discussed in the following sections.

2.1 UTILIZATION OF INDUSTRIAL WASTE SLAG AS AGGREGATE IN CONCRETE MIX

Naik (2002) stated that byproducts have been successfully used in concrete. These materials include used foundry sand and cupola slag from metal-casting industries. Cupola slag has also been used as coarse aggregate in concrete. The density (1280 kg/m^3) of cupola slag is between that of normal weight aggregate (1600 kg/m^3) and structural lightweight aggregate (1120 kg/m^3). The absorption for cupola slag was lower than that for the structural lightweight aggregate. Air-cooled foundry slag was used in concrete as a replacement (50% and 100%) for the coarse aggregate, and foundry sand was used as a partial replacement (up to 35%) of the fine aggregate for masonry blocks and paving stones.

Zeghichi (2006) reported that the choice of aggregates is important, their quality plays a great role, they can not only limit the strength of concrete but owing to their characteristics, they affect the durability and performance of concrete. When the slag is allowed to cool slowly, it solidifies into a grey, crystalline, stony material, know as air cooled, or dense slag as shown in Fig. 2.1. This forms the material used as a concrete aggregates, it is a real silico calcareous rock, similar to the basalt, of angular aspect, rugous and of micro alveolar structure. When the molten slag is chilled very rapidly either by pouring into a large excess of water, or by subjecting the slag stream to jets of water. The quenching breaks up the material into small particles, solidifies as a glass. The product is called granulated slag and is used as cement, or as sand for concrete. The granulated slag can replace the natural sand in concrete; the same can be said about the crystallized slag, which after crushing constitutes excellent normalized gravels. Zeghichi reported that the compressive strength increases with the age of sample. The improvement of strength for the mix with 30% of granulated slag, over the reference concrete at all ages was reported. There was an increase in strength at an early age (3 days) for the 50% granulated slag mix and similar trend was noticed at all other ages. The total substitution of sand by granulated slag caused a decrease in strength at early ages. Slag is a real binder, during the hydration of Portland cement the $Ca(OH)_2$ enters in reaction with slag components, forming the CSH, which playing the role of filling empty spaces in binding medium thus reinforcing the concrete structure.

Fig. 2.1 Cupola Furnace Slag

Xiong et al. (1992) reported that the concrete prepared from pozzolanic slag activated by alkali has excellent mechanical properties and durability, turning the slag into a resource. During cement production, it can lower the environmental load and increase the utilization rate of the slag due to low energy consumption without emission of CO_2 and using the mixed slag. During concrete production, the aggregate with high content of silt and powders can be used along with sea sand and powder sand.

Behera et al. (2011) studied the variation in strength of concrete with percentage of slag. The percentage increase in weight for the specimen prepared using slags for various mixes viz. M20, M40, M60, M80, M100, with respect to natural aggregate was found to be very nominal while the percentage increase in compressive strength was found to be 3.26%, 10.87%, 17.39%, 26.09% and 34.78% respectively. It was observed that, when natural aggregate is substituted completely with slag weight increases only by 6.04% while compressive strength increases up to 34.78%.

Nadeem, and Pofale (2012) found that the compressive strength of concrete increased by 4% to 6% for replacements of both coarse and fine aggregates from 30% to 50%. The mixing of slag and casting of concrete blocks is shown in Fig. 2.2 and 2.3 respectively. However, in case of coarse aggregate the compressive strength increased by 5% to 7% and decreased in case of fine aggregate by 7% to 10% at 100% replacement over control mixes in M20, M30 and M40 grade of concrete.

Fig. 2.2 Mixing of slag

Fig. 2.3 Production of concrete blocks

The 100% replacement of normal crushed coarse aggregate with slag aggregate improved the flexure and split tensile strength by about 6% to 8% in all mixes. The improvement in strength was attributed to the rough surface texture which ensured strong bonding and adhesion between aggregate particles and cement paste. In case of natural fine aggregate replacement with slag fine aggregate the strength increased by 5% to 6% for 50% replacement but reduced by 6 to 8% at 100% replacements. The reason for reduction in strength for 100% replacement was attributed to the presence of coarser particle sizes which could be overcome by addition of finer materials.

Based on the above conclusions, it could be recommended that slag due to its chemical composition and its chemical inertness soundness of aggregate and concrete, could be effectively utilized as aggregates (coarse & fine) in all the concrete constructions like plain concrete and reinforced cement concrete including pavement concrete either as partial or full re- placements over an observed range of 50 to 100%.

In 2012, U.S. Department of Transportation, Federal Highway Administration stated that Air Cooled Blast Furnace Slag (ACBFS) is one of the most commonly utilized reclaimed construction materials, being used as coarse aggregate in Portland cement concrete (PCC), aggregate in hot-mix asphalt, road base material, and fill. According to the U.S. Geological Survey (USGS) 2009, approximately 5.071 million tons (4.6 million metric tons) of ACBFS were used in the United States in 2009, having a value of about $33 million. This number is down from 7.606 million tons (6.9 million metric tons) of ACBFS produced in 2008, having a value of about $53 million, reflecting the dramatic downturn in the U.S. economy. Also, economic savings may be realized due to its lower unit weight, which reduces trucking costs. It also lowers the weight for a given volume of concrete compared to more dense natural aggregates and, due to the vesicular nature of ACBFS producing a rough, porous surface, its bond with cement mortar is good, but workability requirements may involve slightly more mortar (cementitious material, sand, and water) during proportioning. The ladle containing blast furnace slag is shown in Fig. 2.4.

Fig.2.4 Ladle containing blast furnace slag

Ramesh et al. (2013) demonstrated that the furnace and welding slag can be utilized as the building materials in addition to concrete. Welding Slag and Furnace Slag concretes gave better performance towards compressive strength. The compressive strength on seventh day of concrete cubes increases from 10% to 15% with replacement of sand by Welding Slag. The compressive strength on 28th day of concrete cubes increases from 5% to 15% with replacement of sand by Welding Slag. The results show that 5% of Welding Slag and 10% Furnace Slag replacement with sand is very effective for practical purpose.

Afolayan and Alabi (2013) investigated the potentials of cupola furnace slag in concrete. The compressive strength of the concrete designed using blast cupola furnace slag and granulated cupola slag as a coarse aggregate and partial replacement for cement was studied. A series of experimental studies were conducted involving concrete production in two stages. The first stage comprised of Normal Aggregate Concrete (NAC) produced with normal aggregates and 100% Ordinary Portland Cement (OPC). Meanwhile, the second stage involved production of concrete comprising of cupola furnace slag as aggregates with 100% Ordinary Portland Cement (OPC) as shown in Fig. 2.5 and subsequently with 2%, 4%, 6%, 8% and 10% cementitious replacement with granulated cupola furnace slag that had been grounded and milled to less than 75 μm diameter. The outcomes of compressive strength test conducted on the Slag Aggregate Concrete (SAC) with and without granulated slag cementitious replacement were satisfactory compared to Normal Aggregate Concretes (NAC).

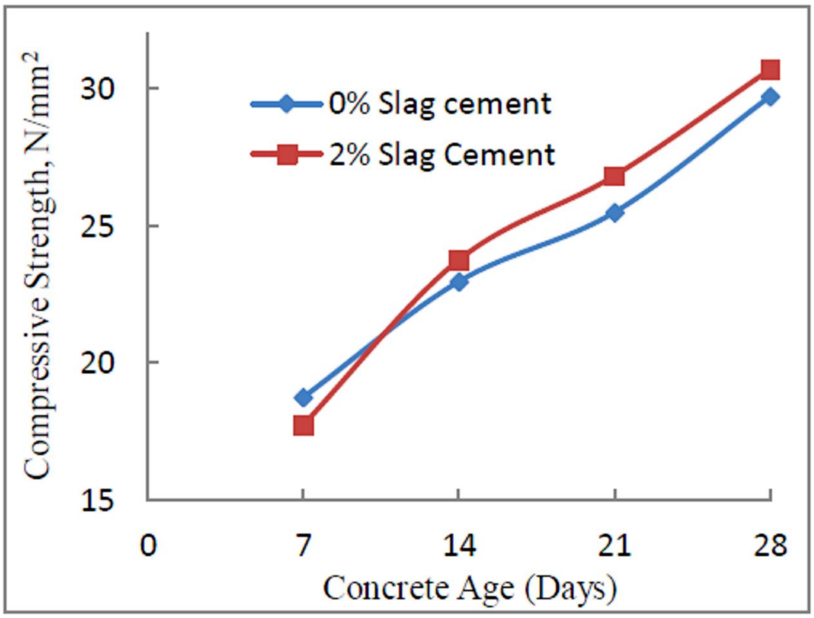


Fig. 2.5 Comparison of slag aggregate concrete (SAC) with and without slag cementitious replacement

Arum and Mark (2014) presented the results of investigation on the potentials of cupola slag as a partial replacement option for Ordinary Portland Cement (OPC) in applications requiring low permeable concrete. The chemical analysis of Granulated Cupola Furnace Slag (GCFS), its fineness, bulk density, specific gravity, and the standard consistency and setting times of binary OPC and GCFS pastes were conducted. Furthermore, concrete mixes of 0.55 water/cement ratio (w/c) were produced using 1:2:4 ratio (volume basis) at 0%, 5%, 10% and 15% replacement levels of OPC by GCFS and the workability and permeability of the fresh concrete were determined. Thirty six standard 150mm cubes were cast from the various concrete mixes, cured for 7, 21 and 28 days and crushed to determine their compressive strengths. The results of the tests showed that within the OPC replacement range investigated, the compressive strength of concrete progressively increased at all curing ages as the replacement level of OPC increased and attained a maximum value of 29.8 N/mm^2 at 28 days for 15% OPC replacement, which amounted to a 31.9% increase above the compressive strength of the reference concrete.

2.2 UTILIZATION OF CUPOLA SLAG AS ROAD BED MATERIAL

Jones (2004) reported that the base course of a road is a layer that needs to be able to provide stable support for the surface layers. A base course can be made up of compacted aggregate, asphalt, or concrete as shown in Fig. 2.6. 100% crushed slag aggregate were tested and were proven as a superior base course material over time, with no other base course material offering so many proven advantages as slag. The density of blast furnace slag is approximately 2.0 T/m^3, and that of steel furnace slag is approximately 2.6 T/m^3. Conventional aggregates in the same product size are 2.1 to 2.3 T/m^3. Slag bases have proven to be more wear resistance along with minimum maintenance and completely stable under all possible moisture conditions. Slag aggregate bases drain better than most conventional aggregates of similar size grading. The depth of base is reduced with slag aggregate because of its high strength.

Fig. 2.6 Utilization of recycled asphalt in road construction

In 2005, Public Works Research Institute in Japan published a technical manual for the use of re-cycled materials generated by other industries in construction projects, which stated that there are two types of molten slag: slowly-cooled slab slag and water granulated slag. In hot asphalt mixtures used for surface and binder courses, slowly cooled slag can be used as a substitute for coarse and fine aggregates, and water granulated slag can be used as a substitute for coarse, fine, or crushed sand, which is used in some cases to replace fine aggregate. The slag can also be used for stability treatment of hot asphalt. Water-granulated slag has been more often used as a fine aggregate in hot asphalt mixture.

Andrews et al. (2012) obtained cupola furnace slag samples from two small scale foundries (Horoos and Abudia foundries) located in the Kumasi metropolis. The chemical compositions of the slags were determined using X-ray fluorescence spectroscopy. The investigated slags were free from CaO and MgO and therefore could be used for road bed construction as shown in Fig. 2.7.

Fig. 2.7 Utilization of slag as road bed material

2.3 UTILIZATION OF SLAG AS AN INSULATION MATERIAL

Jones (2004) reported that blast furnace slag had many of the ingredients of mineral wool and is a principal raw material for its manufacture. Some other minerals are blended with coarse slag, together with coke as a fuel source, and melted in a cupola furnace, by forcing in air to burn the coke. The liquid is then metered out through a restricted opening over high speed rotating cylinders that throw it into the air, forming fibres that solidify and fall onto a pile or a moving conveyor to form a blanket. This fibrous product, either in bulk or blanket form, is an absolutely non-flammable inert insulation material with high heat resistance, is also commonly used in pressed ceiling tiles.

Joulazadeh and Joulazadeh (2010) discussed that the slag can be used as an insulation material, known as slag wool. Slag wool is manufactured by adding auxiliary raw materials to air cooled blast furnace slag, adjusting constituents, melting the mixture in a cupola or an electric arc furnace and finally fibre zing it with special devices like spinner. The fibres are elongated by jet of air, steam or flame. The product is cured in ovens and formed into familiar insulation bats and blankets or chopped into loose-fill insulation used home, commercial and industrial buildings. The manufacturing process of slag wool is shown in Fig. 2.8.

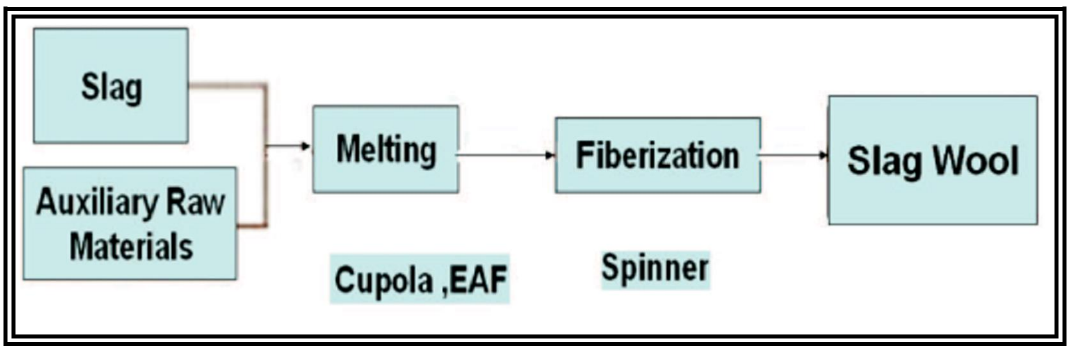


Fig. 2.8 Manufacturing process of BF slag wool

The slag wool has a wide range of applications as heat insulating material, fire-proof wall material for houses, heat reserving and sound absorption materials for industrial applications. The fibres are non-combustible and have melting point over 1100 ^{0}C, they are used in protection against fire.

2.4 UTILIZATION OF SLAG IN GLASS CERAMICS

Agarwal and Speyer (1992) reported that the environmental and economic considerations led to explorations of technologies that allowed the use of slag as raw materials for commercial products. The work gave the procedure for the production of glass ceramics based on blast furnace slag.

Salman and Darwish (2005) discussed the utilization of slag for the production of glass ceramics. The blast furnace slag is highly susceptible to devitrification to the extent that no monolithic glassy phase could be obtained even through the granulation process. Any composition for a glass-ceramic requires only the ability to form a glass and control its crystallization into the favourable fine-grained microstructure. Therefore, in order to obtain a stable glass from slag, it is necessary to decrease the diffusion rate throughout the slag-based glass by increasing its viscosity. This may reduce either the rate of nucleation or crystallization; or at least minimize the temperature zones of their overlapping. The addition of granite to slag is satisfying these requirements.

2.5 UTILIZATION OF SLAG IN CEMENT PRODUCTION

Lewis (1981) reported that the combinations of ground granulated slag and lime were the earliest cements made from slag. Slag cement production began in U.S. in 1896 and the industry grew rapidly, reaching production of over 500,000 barrels annually soon after 1907. The cement was produced at a number of locations, including Birmingham, Chicago, Youngstown, Sparrows Point and Sharon. It was marketed under a number of names including PuzzoIan and Portland. The first specification for slag cement in the U.S. was prepared by the Corps of Engineers in 1902 and covered PuzzoIan Cement, made by "grinding together without subsequent calcination granulated blast-furnace slag with slaked lime. The Blast furnace slag cements have a long history of successful use in all types of applications and develop strengths in either air or water, and in rich or lean mixes, that equal those obtained with Portland cements. The sulfides in the cement disappear without causing any expansion or instability of any kind. Blast-furnace slag cements provide a similar protection for embedded steel as to other cements; with no objections to their use for reinforced structures. Resistance of slag cements to freezing-and-thawing is similar to that of Portland cements with conflicting claims regarding effects of cement composition. The cement itself is, at most, a minor factor apart from effects on air-entrainment and the air-void system in the cement paste. Slag cements are more resistant to sea water and other chemical agents than ordinary Portland cements, having properties similar to those of good sulfate-resistance Portland. Sulfate resistance is affected by the alumina content of the slags, with high alumina slag (about 17%) reported to decrease sulfate resistance at low percentages of cement replacement (50% or less). Low alumina slags (11%) seem to increase sulfate resistance at all levels of use. With high replacement levels (65% or more) all slags increase the sulfate resistance compared to the Portland cement used with them. Expansion of concretes made with alkali-reactive aggregates is considerably reduced by use of slag cements as compared to Portland cement with the same alkali content. Cement performance is greatly dependent upon the permeability that controls the rate of penetration of the chemicals, low permeability is essential for long-term durability. It is concluded that Pozzolan additions to Portland cement or use of blended cements containing large proportions of granulated blast-furnace slag improves the impermeability of concrete by reducing the volume of large pores in the hydrated cement paste.

Kumar et al. (2006) documented that the cement industry is material and energy intensive. Typically, 1–1.5 tonnes of limestone and 0.5 tonnes of coal are used per tonne of clinker produced. Specific energy consumption in cement manufacturing amounts to 4000 MJ/tonne of cement with nearly 80% contributions arising from thermal energy (mostly for clinker formation) and rest from electrical energy (major contribution arising from grinding). In addition, 0.8–1 tonne of CO_2 is generated per tonne of clinker formation. Replacement of clinker with industrial wastes, such as fly ash and granulated blast furnace slag is practiced world over for resource conservation, reduce energy consumption and minimize CO_2 emission. The type of cement that uses fly ash and granulated blast furnace slag as partial replacement of clinker is known as blended cement. India is the second largest producer of the cement in the world. With its current level of production exceeding 110 million tonnes per annum, the country ranks only next to China. In India, blended cements containing 20–25% fly ash, and nearly 40% blast furnace slag are produced. The fly ash and the slag produced in the country amount to 110 and 12–15 million tonnes, respectively. 10-12% fly ash and 40–50% slag are utilized in blended cement manufacturing and there is significant scope to increase the utilization of these wastes in blended cement manufacturing.

Joulazadeh and Joulazadeh (2010) reported that the Sepahan Cement Company was established in 1969 near to ESCo plant and has been employing two production lines to produce Portland cement using slag of ESCo blast furnaces. BF slag cement with 20-40% slag content was used in general constructions. BF slag cement with higher amount of BF slag was used where the heat of concrete hydration was required to be minimized, where increased resistance against chloride ion, sulfate or sea water attack, is necessary, or reduce likelihood of aggregate reaction. The above mentioned company is used 15% BF slag in its cement products. Its cement production capacity was roughly 2.5 million tons per annual. The main characteristics of BF slag are:

- Suitable for erection massive concrete constructions such as dams due to its low heat of hydration.
- Suitable for sewage facilities, offshore constructions.
- It is better in long term strength than Portland cement.
- Effective to control alkali aggregate reaction.

- Excellent water resistance due to greater compactness of hardened concrete with ordinary Portland cement.

2.6 UTILIZATION OF SLAG AS ROOFING MATERIAL

Jones (2004) reported that blast furnace slag is a preferred product for use in built-up roofing systems where aggregate is used to protect and preserve the roofing bitumen from the effects of the weather. Blast furnace slag provides greater bonding with the roofing bitumen than conventional aggregates. Durability of blast furnace slag is excellent: it performs well in freezing and thawing and sulphate soundness tests. Blast furnace slag is light in weight; high reflectivity, better insulation value, and higher fire resistance for use in built-up roofing systems.

Hutchinson (2010) discussed about the production of stone wool. Stone wool raw materials are basalt stone and slag, with slag being a byproduct of the steel industry. Stone wool has in some cases recycled content up to 40%. The process is a complex one that involves converting raw rock and slag into stone wool and then into a product conducive to providing thermal, fire, and sound-resistant properties, all while being dimensionally stable and an appropriate surface for roofing.

National slag Association, US reported that Slag is preferred material for housing roofs especially in California. It is used exclusively at the Rossmore Leisure world developments at Laguna Hills and EI Toro, California. Slag continues to be used because it has demonstrated by in place performance that its claim of excellence is factual. Slag is preferred for large industrial building roofs. An example is the large automotive assembly plant constructed in Talboville, Ontario, Canada in 1965-66, which makes use of 3000 tons of slag on its 15, 00,000 sq. ft. roof.

2.7 UTILIZATION OF SLAG AS AN AGRICULTURAL LIMING MATERIAL

Joulazadeh and Joulazadeh (2010) reported that BF slag has been utilized principally as a raw material for silicate fertilizers. Additionally, BF slag contains such fertilizer component as lime and magnesia as well as Fe and B. silicate fertilizers, popularly known as silicate-calcium fertilizers are widely recognized for good result with aquatic rise. For farms lime, magnesia and silicates abundant in BF slag, improve the chemical properties of soil. Farmer use agricultural slag for maximum yields of cultivated crops and pasture. Parks, golf courses and lawns need to correct soil acidity in order to assure optimum benefit of applied fertilizer. Agricultural slag flows easily though lawn spreads. Nurseries and greenhouse use agricultural slag in making rich soil for plant beds and strip mining need a liming material to neutralize high soil acidity.

National Slag Association, US reported that the benefit to agricultural crop production and soil fertility of having proper levels of alkalinity has been well-established. People in all types of cultivation periodically add liming material to their soil to attain proper pH value. They also recognize the need for adding minor elemental nutrients, such as boron. Soil tests determine how many tons per acre of liming material and nutrients to apply. In areas where iron and steel are manufactured, an agricultural blast-furnace slag product may be available as an economical alternative to agricultural limestone or dolomite and as a better source of minor nutrients.

Ag-Slag is more often coarser than limestone but should be adequate to maintain proper levels of soil pH. The acid soil problem can be corrected by using a finer graded agricultural slag material. It is also easier to spread, particularly in a damp condition. Because agricultural slag corrects soil acidity by a slightly different chemical reaction, the CCE test procedure in ASTM C-602 specification, Agricultural Liming Materials, is slightly different for slag than it is for limestone, as recommended by the Association of Agricultural Chemists. Based on soil tests and the desired crop, the application of a magnesium-bearing, liming aid is usually recommended. Presently, Ag-Slag with 10-14% magnesia (MgO) is sufficient.

2.8 UTILIZATION OF SLAG AS ALL WEATHER RIDING SURFACE

Environmental Technology Best Practice Programme, UK (1999) showcased an example to show the utilization of slag as all weather riding surface. Potterton Myson Ltd specialize in the production of grey-iron heat exchanger castings for its own central manufacturing facility and pump body castings for Myson Pumps, part of its heating group. For over 15 years, the foundry has avoided sending its granulated cupola slag to landfill by supplying it to local horse riding centers to provide an all-weather outdoor surface shown in Fig. 2.9.

Approximately 7.5 tonnes/week of liquid slag from the foundry's 8 tonnes/hour cupolas is discharged directly into flowing water. The slag granulates on contact and then flows into two settling tanks. The settling tanks are drained periodically and the slag is excavated and stockpiled in a designated storage area until suitable quantities are obtained. When a suitable quantity is available, the granulated slag is supplied to the riding centres in 15-tonne lorry loads using a covered tipper truck and approximately 60 - 70 tonnes are taken at a time. A charge of £20/load is made to cover transport and handling costs. There is no processing required to make the granulated slag suitable for re-use. It is a particularly low-cost and effective method of re-use for both the foundry and the end-user because there is no third party involved. Traditionally, riding schools have used other by-products, such as wood chips or processed rubber tyres, for running surfaces but the slag is a preferred material for this purpose. The popularity of using slag is growing and Potterton Myson currently supplies several local riding schools. The local nature of this re-use opportunity and the long-term demand for small volumes of material make it particularly suitable for the foundry.

Fig. 2.9 Utilization of slag as riding surface

2.9 UTILIZATION OF SLAG AS SLURRY SEALS

National Slag Association, US published that the slurry seals were developed, in the late 1920's and the early 1930's. Using an asphalt emulsion with a fine aggregate and filler, a "slurry" or semi-fluid mix was prepared, usually in a transit mix truck. In 1960, the first commercially available self-contained machine to continuously mix and spread slurry seals was placed in operation. This permitted quick proportioning, mixing, and placing of the slurry before the emulsion started to break, thus improving adhesion to the old surface. Three types of slurry seal mixes are commonly used with variations in aggregate grading, asphalt content and application rate. Type I aggregate blend is used to seal cracks, fill small voids, and correct moderate surface deterioration and/or general drying or hardening of surface asphalt. Type II aggregate blend is the most commonly used in slurry seal work and most closely corresponds to the grading of most slag screenings. They are used when it is desired to fill surface voids, correct surface erosion and raveling, and provide sealing and a thin wearing surface. Type III aggregate blend uses aggregates up to 3/8" in size and are applied at rates above 15 lb/sq yd. Major applications are for extremely rough textured pavements where a larger size of aggregate and a greater slurry thickness are necessary to fill in the voids and provide a moderate thickness wearing course. They may also be used in two course construction to correct the crown in a pavement or to provide a wearing course on various types of stabilized bases including soil cement.

2.10 MAJOR OBSERVATIONS FROM THE LITERATURE REVIEW:

From the literature review, it is observed that a lot of work has been done in this field. Following are the points which can be concluded from the literature review:

- ❖ The slag can be utilized as a replacement to aggregate in all the concrete constructions like plain concrete and reinforced cement concrete. During the experimental tests, it has been found that the replacement of both coarse and fine aggregates along with slag would result in increase in the compressive and tensile strength of concrete by 4% to 6%.
- ❖ The experimental study on the use of slag as aggregate material has confirmed that the percentage increase in weight of the specimen prepared with respect to natural aggregate is found to be very nominal while the percentage increase in tensile and compressive strength is found to be on the higher side. The improvement in strength was attributed to the rough surface texture which ensured strong bonding and adhesion between aggregate particles and cement paste.
- ❖ The study of the chemical and mineralogical characterization of the cupola furnace slag confirms that it can be useful as road bed material besides using it as soil fertility improver.
- ❖ The slag can be used as a raw material for the production of slag wool along with the use of other auxiliary raw materials. The slag wool is an absolutely non-flammable inert insulation with high heat resistance which can be used in industrial buildings.
- ❖ The slag can also be utilized in the formation of blended cement as a partial replacement to the clinker, which is utilized in the production of cement. The study on the use of slag in the formation of blended cement reveals that 40–50% slag is utilized as a partial replacement

to the clinker material which not only utilizes the slag but also conserve the natural resources which are otherwise required for the production of clinkers.

- The blast furnace slag can be substituted as a raw material for improving the fertility of soil as it contains the fertilizer component such as lime and iron. Also, it can be used to improve the chemical properties of soil and it can also helps in improving the soil texture.
- The slag can also be utilized in the form of slurry seals which is a kind of semi fluid mix used to seal the cracks, fill small voids and correct minor surface deterioration of the road surface.

The objective of the present study is to utilize the Cupola furnace Slag, obtained from the foundry industry available in Punjab, as a partial replacement to coarse aggregate in concrete mix and to study the effect on compressive and split tensile strengths 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. Thus, there is a need to study the chemical composition of cupola furnace slag before partially replacing it as coarse aggregate.

CHAPTER- 3

EXPERIMENTATION

3.0 GENERAL

The present chapter deals with the materials properties and the results obtained from the various tests conducted on the material used for the development of concrete mixes containing cupola furnace slag as partial replacement of coarse aggregates. In order to achieve the objective of the present study, an experiment was conducted to determine the compressive strength and split tensile strength of concrete specimens made by using the prescribed materials in designed proportions.

The experimental procedure has been planned to determine the effect of cupola slag on the compressive and split tensile strength of concrete.

3.1 MATERIALS USED

The properties of various materials used in the study are determined as per the relevant codes of practice ***(Gambhir, 1992).*** The various materials used are cement, coarse aggregate, fine aggregate and cupola furnace slag. The aim of studying the various properties of the materials is to check their validation with the code requirements and to enable an engineer to design a concrete mix for a particular strength.

3.1.1 Portland Cement

Cement is the most important ingredient of the concrete mix as it acts as binding agent between the coarse and fine aggregate. Portland Pozzolana Cement (PPC) is a blended cement which is produced by either inter-grinding of OPC clinker along with gypsum and pozzolanic materials in certain proportions or grinding the OPC clinker, gypsum and Pozzolanic materials separately and thoroughly blending them in certain proportions.

Pozzolana is a natural or artificial material containing silica in a reactive form. It may be further discussed as siliceous and aluminous material which in itself possesses little or no cementitious properties but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide in the presence of water to form stable calcium silicates which have cementitious properties.

The cement used for the present study is PPC Ultra-tech cement and it is preserved from moisture to prevent the deterioration in its properties. The cement used is fresh and free from lumps. The various 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

Sr. No.	**Physical Properties**	**Value**
1.	Specific Gravity	3.12
2.	Soundness	0.5 mm
3.	Initial setting time	92 minutes
4.	Final setting time	137 minutes
5.	Compressive Strength after curing for	
	3 days	23.46 MPa
	7 days	31.63 MPa
	28 days	39.97 MPa

3.1.2 Coarse aggregates

Coarse aggregates are inert granular materials having diameter greater than 4.75mm. They can either be from primary, secondary or recycled sources. Primary aggregates are obtained either from land or from the marine environment. Coarse aggregates include gravel and crushed rock. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder. Secondary aggregates are materials which are the by-products of extractive operations and are derived from a very wide range of materials. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular sub bases, soil-cement, and in new concrete.

The coarse aggregate used in the present work is having the maximum size of 12 mm and it is properly washed to make it dirt free before performing the test for determining its physical properties. The various properties tested are specific gravity, water absorption and sieve analysis. The results obtained are mentioned in Table 3.2 and 3.3.

Table 3.2 Physical properties of coarse aggregate

Sr. No.	Physical Properties	Value
1.	Specific Gravity	2.62
2.	Water absorption	1.69%
3.	Color	Grey
4.	Maximum Size	12mm

Table 3.3 Sieve analysis of coarse aggregate (12mm)

Sr. No.	Sieve no. (mm)	Mass Retained (in kg)	%age Retained	%age Passing	Cumulative % Retained
1.	20	0	0	100	0
2.	12.5	1.168	11.68	88.32	11.68
3.	10	3.305	33.05	55.27	44.73
4.	4.75	4.887	48.87	6.4	93.60
5.	Pan	0.640	6.40	0	
	Total	**10 kg**		SUM = 150.01	

Fineness modulus = 6.50

3.1.3 Fine aggregates

Fine aggregates are basically sand obtained from the land or the marine environment. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through 4.75 mm sieve. As with coarse aggregates these can be from primary, secondary or recycled sources. The various properties tested are specific gravity, water absorption and sieve analysis. The results obtained from the said tests are given in Table 3.4 and 3.5.

Table 3.4 Physical properties of fine aggregate

Sr. No.	Physical Properties	Value
1.	Specific Gravity	2.70
2.	Water absorption	2.24%
3.	Fineness modulus	2.87
4.	Zone	II

Table3.5 Sieve analysis of fine aggregate

Sr. No	Sieve no.	Mass Retained (in grams)	%age Retained	%age Passing	Cumulative % Retained
1.	4.75mm	9.00	0.9	99.1	0.9
2.	2.36mm	94.00	9.4	89.7	10.3
3.	1.18mm	292.00	29.2	60.5	39.5
4.	600 µm	206.00	20.6	39.9	60.1
5.	300 µm	195.00	19.5	20.4	79.6
6.	150 µm	172.00	17.2	3.2	96.8
7.	Pan	32.00	3.2	**SUM**	**287.2**

3.1.4 Cupola slag

The cupola furnace slag is collected from three different foundry clusters of Punjab *i.e.* M/s Greatway Foundry and Engineering Works, Batala, M/s Joshi Motor Parts, Jalandhar and M/s Makhan Sewing Machine, Ludhiana to study the nature and chemical composition of slag.

(a)

(b) **(c)**

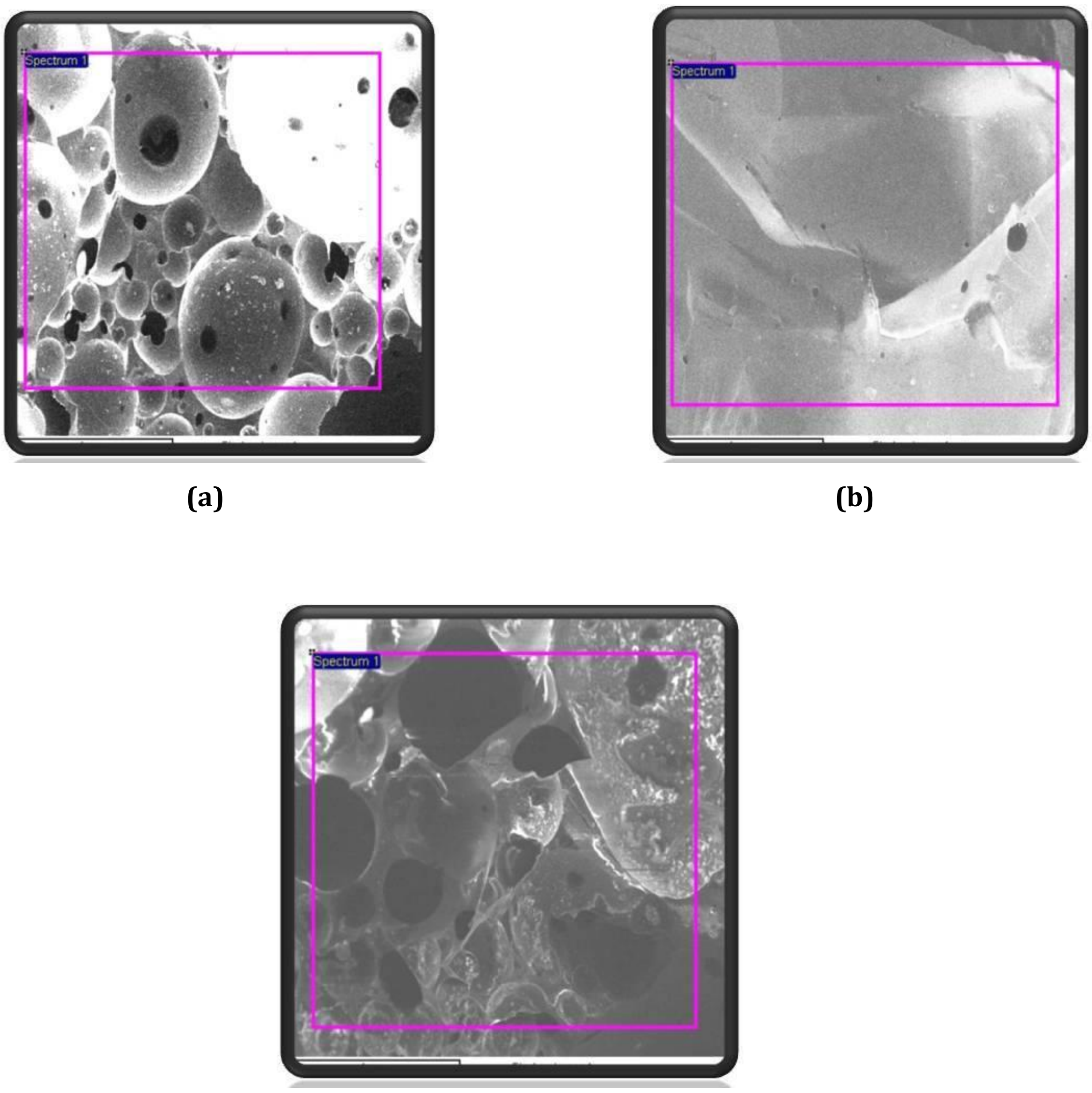
Fig. 3.1 Slag samples from: a) Batala , b) Jalandhar and c) Ludhiana

Fig. 3.1 depicts that there is variation in the size as well as in the color of the slag due to the variation in the operating practices and quality of material used in the cupola furnace.

Fig. 3.2 Scanning Electron Microscope (SEM)

The tests were conducted at SAI Labs, Thapar University, Patiala on Scanning Electron Microscope (SEM), shown in Fig. 3.2.

The SEM results are shown in Fig. 3.3. The analyzed chemical composition of slag samples are given in Table 3.6.



(a) **(b)** **(c)**

Fig. 3.3 SEM images (a) Batala (b) Jalandhar (c) Ludhiana

Table 3.6 Chemical composition of different slag samples

Sr. no.	Compounds	Sample-Batala (in %)	Sample-Ludhiana (in %)	Sample- Jalandhar (in %)
1	MgO	6.02	7.79	6.85
2	Al_2O_3	6.06	16.58	8.86
3	SiO_2	34.97	47.99	42.65
4	K_2O	0.74	0.56	0.92
5	CaO	19.36	24.33	21.84
6	MnO	3.26	1.19	3.69
7	FeO	29.59	1.56	15.19

The chemical composition of the different cupola furnace slag sample varies and this variation depends on the coke quality, contamination of charging material and quantity as well as quality of lime stone used in cupola furnace. The chemical composition reveals that values obtained for Jalandhar slag sample have SiO_2, CaO, MgO and Al_2O_3 lying in between the values obtained for Batala and Ludhiana slag samples. Therefore, the Jalandhar slag sample is considered as reference sample for further study.

The various physical properties of cupola slag studied are specific gravity, water absorption and sieve analysis. The results obtained are mentioned in Table 3.7 and 3.8.

Table 3.7 Physical properties of slag

Sr. no.	Physical Properties	Value
1.	Specific Gravity	2.31
2.	Water Absorption	1.07 %

Table 3.8 Sieve analysis of Slag

Sr. No	Sieve no. (mm)	Mass Retained	%age Retained	%age Passing	Cumulative % Retained
1.	20	0.556	5.56	94.44	5.56
2.	12.50	1.186	11.86	82.58	17.42
3.	10	2.900	29	53.58	46.42
4.	4.75	4.680	46.80	6.78	93.22
5.	Pan	0.678	6.78	**SUM**	**162.61**
	Total	**10 kg**		**F.M.**	**6.626**

3.2 TEST PERFORMED

The following are the different test performed for finding the physical properties of Portland cement, Coarse aggregate, Fine aggregate and Cupola slag as per concrete manual (Gambhir, 1992).

3.2.1 Specific gravity

Specific gravity is the ratio of the weight of a given volume of substance to the weight of an equal volume of some reference substance or equivalently the ratio of the masses of equal volume of two substances.

3.2.2 Sieve analysis for coarse and fine aggregate

The sieve analysis is performed to determine the particle size distribution of coarse and fine aggregate by sieving and finding out their fineness modulus thereon.

3.2.3 Compressive strength of concrete

The cube specimens of size 150mm x 150mm x 150mm are casted shown in Fig. 3.4 to determine the compressive strength of concrete. The materials *i.e.* cement, coarse aggregate, fine aggregate and cupola slag are properly weighed as per the calculated mix design for different water cement-ratio (w/c) and thoroughly mixed to get the uniform mixture. The quantity of water added in the dry mixture as per the respective mix design to make it in slurry form. The concrete mix is filled in the cube moulds are vibrated to ensure proper compaction. The top surfaces of the mould are properly finished by making use of trowel. The finished specimens were left to harden in air for a period of 24 hours. The specimens are removed out from the mould after 24 hours of casting and placed in water tank for curing period of 7 and 28 days.

Fig. 3.4 Casting of Cubical blocks

The cube specimens are casted for different water cement ratio by partially replacing the coarse aggregate with cupola slag in proportion of 10%, 20%, 30% and 40%. The specimens are tested for compressive strength after curing period of 7 and 28 days. The specimen is placed in the Universal Testing Machine and the load is applied gradually without any shock till the failure of the specimen and thus compressive strength is found as shown in Fig. 3.5.

3.2.4 Split tensile strength of concrete

The split tensile strength of concrete is tested by casting cylinders as shown in Fig. 3.6 of size 150mm x 300mm. The materials *i.e.* cement, coarse aggregate, fine aggregate and cupola slag are properly weighed as per the calculated mix design for different water-cement ratio and thoroughly mixed to get the uniform mixture. The quantity of water is added in the dry mixture as per the respective mix design to make it in slurry form. The concrete mix filled in the cylinder moulds are vibrated to ensure proper compaction. The top surface of the mould is properly finished by making use of trowel. The finished specimens were left to harden in air for a period of 24 hours. The specimens are removed out from the mould after 24 hours of casting and placed in water tank as shown in Fig. 3.7 for curing period of 7 and 28 days.

Fig. 3.5 Testing of compressive strength

The cylinder specimens are casted for different water-cement ratio by partially replacing the coarse aggregate to that cupola slag in proportion of 10%, 20%, 30% and 40%. The specimens are tested for split tensile strength after curing period of 7 and 28 days. The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading is given by:

$$T = \frac{0.637P}{DL} \qquad \text{........ (3.1)}$$

Where,

P = Applied load (kN)

D = Diameter of concrete cylinder specimen (mm)

L = Length of concrete cylinder specimen (mm)

The specimen is placed in the Universal Testing Machine (UTM) and the load is applied gradually without any shock till the failure of the specimen and thus split tensile strength is found. The testing of specimen is shown in Fig. 3.8.

Fig. 3.6 Casting of Cylindrical blocks

Fig.3.7 Curing of blocks in water tank

Fig. 3.8 Testing of split tensile strength

3.3 MIX DESIGN

Mix design is formulated with different water-cement ratio (w/c) on the basis of the various tests performed on the materials. The various mixes are designed for prefixed water-cement ratios of

0.40, 0.45 and 0.50. Subsequently the proportions of coarse aggregates obtained for the designed mixes is partially replaced with cupola furnace slag aggregate in the prefixed proportions of 10, 20, 30 and 40%.

3.3.1 Test data of materials:

Mix design is formulated using the IS10269 mix design code, on the basis of test data of materials shown in Table 3.9:

Table 3.9 Test data of materials

Sr. No.	Description	Value
1.	Specific gravity of cement	3.22
2.	Specific gravity of coarse aggregate	2.62
3.	Specific gravity of fine aggregate	2.70
4.	Water absorption of coarse aggregate	1.69
5.	Water absorption of fine aggregate	2.24

The mix proportion obtained for the various mix are tabulated below:

Table 3.10 Mix Design for water-cement ratio (w/c) of 0.50

Sr. No.	w/c ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Cupola slag (kg/m^3)
1.	0.50	180	360	717.6	1144.58	0
2.	0.50	180	360	717.6	1030.12	100.92
3.	0.50	180	360	717.6	915.67	201.83
4.	0.50	180	360	717.6	801.20	302.74
5.	0.50	180	360	717.6	686.74	457.83

Table 3.11 Mix Design for water-cement ratio (w/c) of 0.45

Sr.no.	w/c ratio	Water (kg/m³)	Cement (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Cupola slag (kg/m³)
1.	0.45	180	400	685.98	1141.88	0
2.	0.45	180	400	685.98	1027.69	100.68
3.	0.45	180	400	685.98	913.50	201.35
4.	0.45	180	400	685.98	779.31	302.03
5.	0.45	180	400	685.98	685.12	456.75

Table 3.12 Mix Design for water-cement ratio (w/c) of 0.40

Sr.no.	w/c ratio	Water (kg/m³)	Cement (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Cupola slag (kg/m³)
1.	0.40	170	425	669.36	1163.34	0
2.	0.40	170	425	669.36	1047.0	102.60
3.	0.40	170	425	669.36	930.67	205.14
4.	0.40	170	425	669.36	814.33	307.71
5.	0.40	170	425	669.36	698.0	465.33

CHAPTER- 4

RESULTS AND DISCUSSIONS

4.0 GENERAL

The main objective of the present work is to investigate the strength characteristics of concrete obtained using cupola slag as partial replacement to coarse aggregate. In order to achieve the objectives, an experimental procedure was planned to investigate the impact of cupola slag on compressive and split tensile strength of concrete specimen. The experimental procedure consisted of casting, curing and testing of concrete specimen with and without cupola slag at different curing ages. The experimental procedure included:

- Testing of material properties.
- Mix Design.
- Casting and curing of specimen.
- Tests to determine the compressive strength of concrete specimen
- Tests to determine split tensile strength of concrete specimen.

The following section deals with the presentation of results obtained from various tests conducted on concrete specimens with and without cupola furnace slag.

4.1 COMPRESSIVE STRENGTH

In most structural applications, concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place in its vertical plane along the diagonal. The vertical cracks occur due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member, will take place on the application of axial compression load and propagate further due to lateral tensile strains.

Test specimens (3 each) of 150mm x 150mm x 150mm were cast for testing the compressive strength of concrete at different water-cement ratio. The concrete mix with varying quantity of cupola slag *i.e.* 10%, 20%, 30% and 40% as partial replacement to coarse aggregate were cast and tested after curing period of 7 and 28 days.

The results obtained after curing period of 7 and 28 days for water-cement ratio of 0.50, 0.45 and 0.40 are mentioned in Table 4.1, 4.2 and 4.3.

Table 4.1 Compressive Strength of Concrete Mixes with w/c of 0.50

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	19.17	19.73	21.30	24.30	18.90
2.	28	30.60	33.30	35.80	38.10	31.80

Table 4.2 Compressive Strength of Concrete Mixes with w/c of 0.45

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	23.90	24.80	25.80	28.80	23.80
2.	28	34.50	35.80	38.40	41.10	33.60

Table 4.3 Compressive Strength of Concrete Blocks with w/c of 0.40

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	31.50	32.10	33.50	35.50	25.50
2.	28	45.50	48.50	50.60	52.40	42.50

It can be observed from the above results that the compressive strength of the concrete increases by incorporating cupola slag up to 30% as partial replacement to coarse aggregate in all the concrete mixes and subsequently decreases on further increase in the cupola slag concentration in the concrete specimen. The results are plotted graphically for curing period of 7 and 28 days as shown in Fig 4.1 and 4.2.

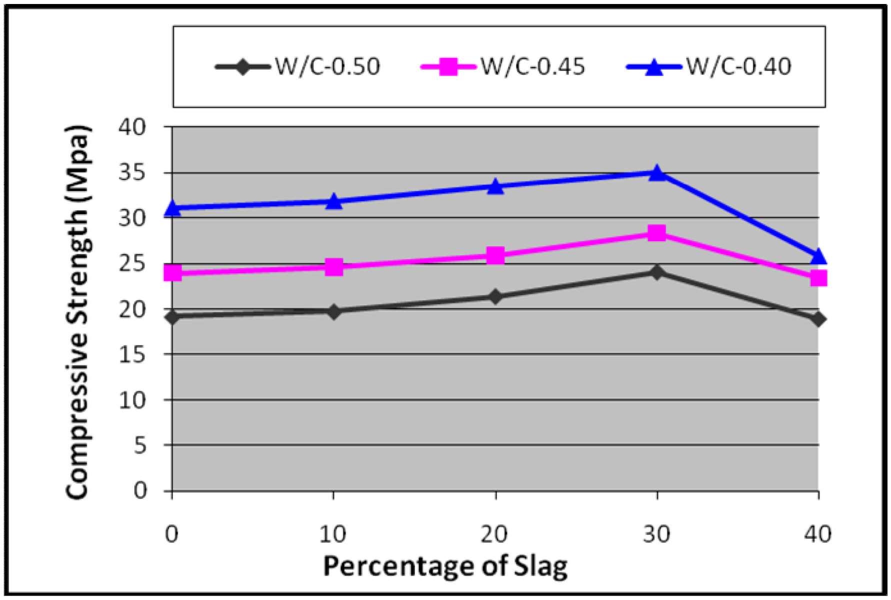


Fig. 4.1 Compressive strength of concrete specimen (7 days)

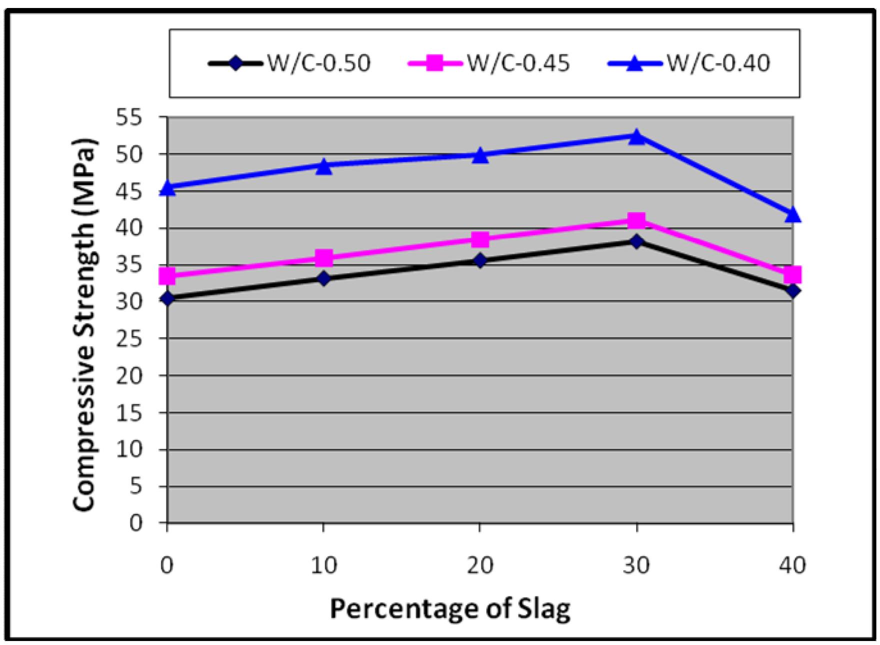


Fig. 4.2 Compressive strength of concrete specimen (28 days)

The result obtained indicate that the replacement of 10% coarse aggregate with that of cupola slag leads to a very minor increase in compressive strength by 2.97%, 2.63% and 2.37% for w/c of 0.50, 0.45 and 0.40, respectively after a curing period of 7 days. Similarly, a replacement of 20% coarse aggregate with cupola slag leads to an increase in compressive strength by 11.69%, 8.02% and 7.74% for w/c of 0.50, 0.45 and 0.40, respectively. Furthermore, a replacement of 30% of coarse aggregate with that of cupola slag leads to an increase in compressive strength by 25.57%, 18.38% and 12.56% for w/c of 0.50, 0.45 and 0.40, respectively after curing period of 7 days.

Also for the 28 days curing period, a replacement of 10% coarse aggregate with that of cupola slag leads to increase in compressive strength by 8.85%, 7.29% and 6.21 % for w/c of 0.50, 0.45 and 0.40, respectively. Similarly, a replacement of 20% coarse aggregate with that of cupola slag leads to increase in compressive strength by 16.81%, 14.79% and 9.50% for w/c of 0.50, 0.45 and 0.40 respectively. Further, a replacement of 30% of coarse aggregate with that of cupola slag leads to increase in compressive strength by 25.34%, 22.62% and 14.95% for w/c of 0.50, 0.45 and 0.40, respectively after curing period of 28 days following a pattern very similar to 7 days strength.

Also it can be observed that the percentage increase in the strength is higher at higher w/c ratios at both ages, thus indicating the suitability of use of cupola furnace slag where strength requirements are low. This increase can be attributed to the fact that the transition zone between the aggregates is improved due the presence of cupola furnace slag, thereby increasing the compressive strength.

It can also be observed that a further increase in percentage of cupola furnace slag beyond 30% results in a decrease in strength to a value below the normal mix. Thus, it can be concluded that the optimum percentage level of replacing coarse aggregates with cupola furnace slag is 30% only.

The percentage increase in compressive strength after incorporating cupola slag is graphically shown in Fig 4.3 and 4.4.

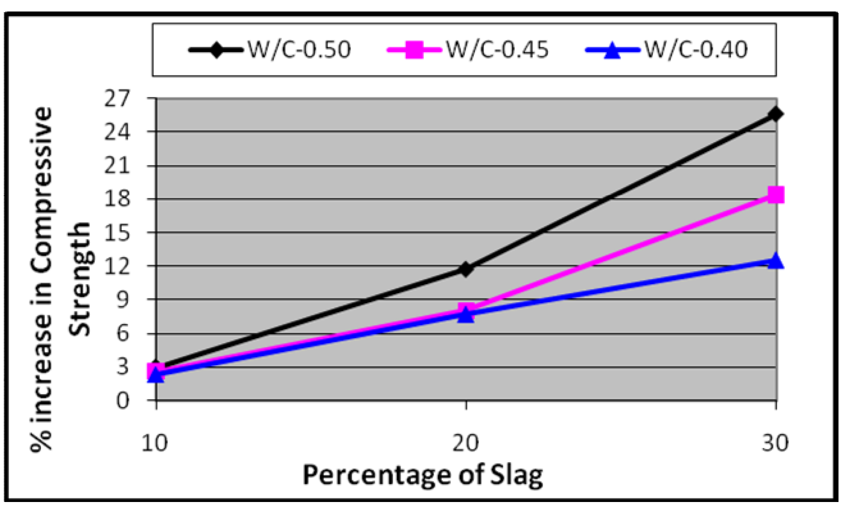


Fig. 4.3 Percentage increase in Compressive strength (7 days)

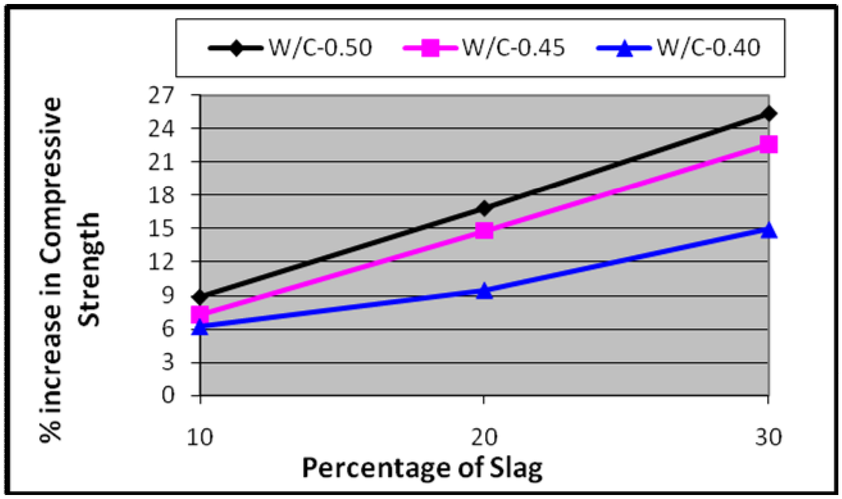


Fig. 4.4 Percentage increase in Compressive strength (28 days)

4.2 SPLIT TENSILE STRENGTH

The split tensile strength of concrete is tested by casting cylinders of size 150mm x 300mm for different water-cement ratio of 0.50, 0.45 and 0.40 for curing period of 7 and 28 days. The results obtained for split tensile strength are given in Table 4.4, 4.5 and 4.6.

Table 4.4 Split Tensile Strength of Cylindrical Blocks with w/c of 0.50

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	2.33	2.38	2.47	2.66	2..11
2.	7	2.28	2.36	2.52	2.70	2.13
3.	7	2.29	2.41	2.50	2.82	2.19
4.	28	3.21	3.47	3.65	3.91	3.22
5.	28	3.27	3.40	3.71	3.87	3.29
6.	28	3.18	3.51	3.69	3.80	3.27

Table 4.5 Split Tensile Strength of Cylindrical Blocks with w/c of 0.45

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	2.40	2.42	2.58	2.79	2.25
2.	7	2.38	2.48	2.55	2.76	2.21
3.	7	2.35	2.45	2.52	2.71	2.19
4.	28	3.58	3.83	3.99	4.10	3.42
5.	28	3.69	3.89	3.90	4.19	3.50
6.	28	3.62	3.81	3.97	4.12	3.49

Table 4.6 Split Tensile Strength of Cylindrical Blocks with w/c of 0.40

Sr. No.	Curing Period (days)	Normal mix (MPa)	Coarse aggregate replacement with slag			
			10% (MPa)	20% (MPa)	30% (MPa)	40% (MPa)
1.	7	2.60	2.67	2.78	2.90	2.43
2.	7	2.64	2.69	2.76	2.97	2.47
3.	7	2.62	2.73	2.81	2.94	2.40
4.	28	4.11	4.37	4.40	4.62	4.09
5.	28	4.19	4.25	4.46	4.59	4.13
6.	28	4.16	4.33	4.39	4.68	4.21

It can be observed from the above results that the split tensile strength of the blocks is increased by incorporating cupola slag up to 30% as partial replacement to coarse aggregate in all the concrete mixes and this value declines further by increasing the cupola slag concentration in the concrete specimen. The results are plotted graphically by considering average reading of split tensile strength for curing period of 7 and 28 days as shown in Fig 4.5 and 4.6.

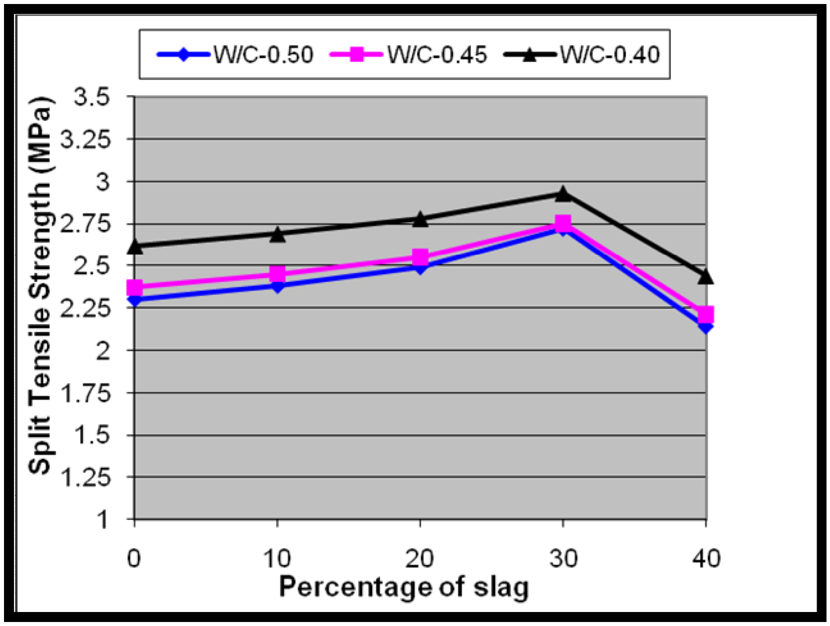


Fig. 4.5 Split tensile strength of concrete specimen (7 days)

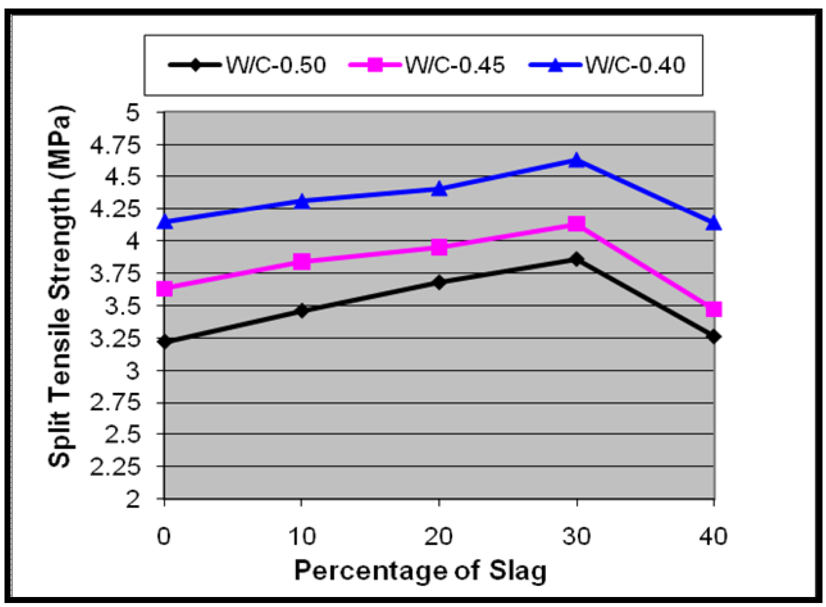


Fig. 4.6 Split tensile strength of concrete specimen (28 days)

The results obtained indicates that a replacement of 10% coarse aggregate with that of cupola slag leads to an increase in split tensile strength by a very small amount of 3.47 %, 3.37 % and 2.67% for w/c of 0.50, 0.45 and 0.40 respectively after curing period of 7 days. Similarly, a replacement of

20% coarse aggregate with that of cupola slag leads to an increase in split tensile strength by 8.26%, 7.59% and 6.10% for w/c of 0.50, 0.45 and 0.40, respectively. Further, with the replacement of 30% of coarse aggregate with that of cupola slag leads to increase in split tensile strength by 18.26%, 16.03% and 11.83% for w/c of 0.50, 0.45 and 0.40 respectively, after curing period of 7 days as shown in Fig. 4.7. The trend is very similar to that observed for mixes tested for compressive strength.

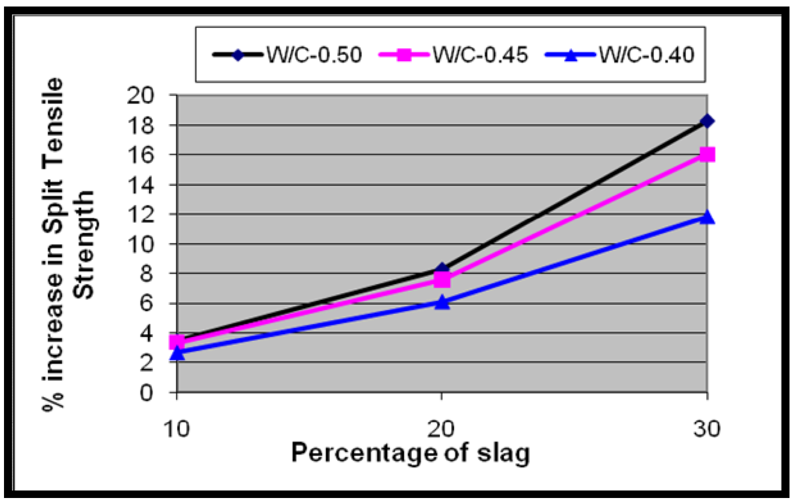


Fig 4.7 Percentage increase in split tensile strength (7 days)

The replacement of 10% coarse aggregate with that of cupola slag leads to an increase in split tensile strength by 7.45%, 5.78% and 3.85 % for w/c of 0.50, 0.45 and 0.40 respectively after curing period of 28 days. Similarly, with the replacement of 20% coarse aggregate with that of cupola slag leads to increase in split tensile strength by 14.28%, 8.81% and 6.26% for w/c of 0.50, 0.45 and 0.40 respectively. Further, with the replacement of 30% of coarse aggregate with that of cupola slag leads to increase in split tensile strength by 19.87%, 13.77% and 11.56% for w/c of 0.50, 0.45 and 0.40 respectively after curing period of 28 days as shown in Fig. 4.8.

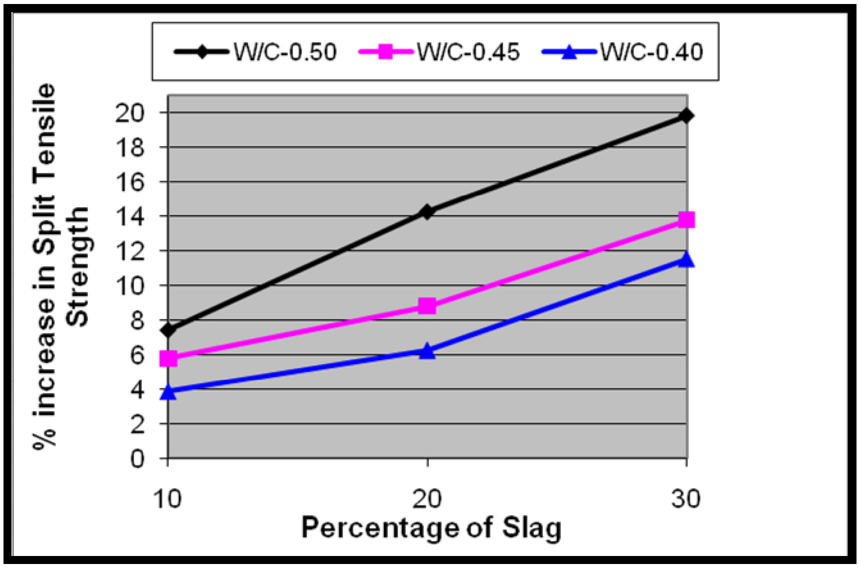


Fig 4.8 Percentage increase in split tensile strength (28 days)

It can be also observed, on similar lines as compressive strength, that the percentage increase in the split tensile strength is higher at higher w/c ratios at both ages, thus indicating the suitability of use of cupola furnace slag where tensile strength requirements are low. This increase can be attributed to the fact that the transition zone between the aggregates is improved due the presence of cupola furnace slag, thereby increasing the split tensile strength.

It can also be observed that a further increase in percentage of cupola furnace slag beyond 30% results in a decrease in strength to a value below the normal mix. Thus, it can be concluded that the optimum percentage level of replacing coarse aggregates with cupola furnace slag is 30% only.

CHAPTER- 5

CONCLUSIONS

5.0 GENERAL

In order to achieve the objective of the present study, an experimental plan was designed to determine the compressive strength and split tensile strength of concrete specimens made by using the prescribed materials in designed proportions, with and without cupola furnace slag.

The compressive and split tensile strength of the concrete blocks have been analyzed in the present work by replacing the coarse aggregate in proportion of 10%, 20%, 30% and 40% with cupola furnace slag. The following major conclusions are drawn from the study:

5.1 COMPRESSIVE STRENGTH

- The compressive strength of the concrete is increased by partial replacement of coarse aggregate up to 30% with cupola furnace slag.
- The percentage increase in compressive strength is higher for higher water-cement ratios indicating its suitability for use in concrete mixes where strength requirements are low for all curing ages.
- Highest increase in compressive strength is achieved for a 30% replacement of coarse aggregates with cupola furnace slag, indicating that 30% cupola slag is the optimum replacement percentage of coarse aggregates in the concrete mixtures.
- The compressive strength of the concrete decreases beyond 30% replacement of coarse aggregate with cupola slag.

5.2 SPLIT TENSILE STRENGTH

- The split tensile strength of the concrete is increased by partial replacement of coarse aggregate up to 30% with cupola furnace slag.
- The percentage increase in split tensile strength is higher for higher water-cement ratios indicating its suitability for use in concrete mixes where tensile strength requirements are low for all curing ages.

- Highest increase in split tensile strength is achieved for a 30% replacement of coarse aggregates with cupola furnace slag, indicating that 30% cupola slag is the optimum replacement percentage of coarse aggregates in the concrete mixtures.
- The split tensile strength of the concrete decreases beyond 30% replacement of coarse aggregate with cupola slag.

5.3 SCOPE FOR FURTHER WORK

- In the present work, the effect of replacement of coarse aggregate by cupola furnace slag is studied on compressive and split tensile strength of concrete. The study can be extended to flexural strength.
- In the present work, the effect of replacement of coarse aggregate by cupola furnace slag has been studied on the strength characteristics. The study can be extended to durability properties as well.
- The effect of partial replacement of fine aggregate with that of cupola slag can also be studied for effect on both strength and durability characteristics.

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