

**EFFECT OF PARTIAL REPLACEMENT OF SAND BY IRON SLAG ON
STRENGTH CHARACTERISTICS OF CONCRETE**

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in partial fulfilment of the requirements for
the award of the degree of

**MASTERS OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

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DECLARATION

The author hereby declares that this thesis entitled "**Effect of Partial Replacement of Sand by Iron Slag on Strength Characteristics of Concrete**", in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work.

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CERTIFICATE

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ABSTRACT

Due to growing environmental awareness, as well as stricter regulations on managing industrial waste, the world is increasingly turning to researching properties of industrial waste and finding solutions on using its valuable component parts so that those might be used as secondary raw material in other industrial branches.

Although iron and steel slag is still today considered waste and is categorized in industrial waste catalogues in most countries in the world, it is most definitely not waste, neither by its physical and chemical properties nor according to data on its use as valuable material for different purposes. Moreover, since the earliest times of the discovery and development of processes of iron and other metals production, slag as by-product is used for satisfying diverse human needs, from the production of medicines and agro-technical agents to production of cement and construction elements.

Considering the specificity of physical and chemical properties of metallurgical slags and a series of possibilities for their use in other industrial branches and in the field of civil constructions, this report demonstrates the possibilities of using iron slag as partial replacement of sand in concrete.

Iron and steel making slag are by products of the iron making and steelmaking processes. To date, these types of slag have been widely used in cement and as aggregate for civil works. The report presents an investigation of mechanical and durability properties of concrete by adding iron slag as replacement of sand in various percentages. The X-ray diffraction analysis carried out in this paper gives a deeper insight in the mineralogical constitution and behavior of such slags when used for construction purposes. The results show that the strength properties of concrete increase significantly when sand is partially replaced by iron slag.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

The history of the use of iron and steel slag dates back a long way. European Slag Association (2006) has reported about the earliest reports on the use of slag, where in it is mentioned that Aristotle used slag as a medicament as early as 350 B.C. All through history use of slag has ranged from the novel to the usual including: cast cannon balls in Germany (1589), wharf buildings in England (1652), slag cement in Germany (1852), slag wool in Wales (1840) armored concrete in Germany (1892) slag bricks made from granulated slag and lime in Japan (1901) according to Iron and Steel (2007). In the past, the application of steel slag was not noticeable because enormous volumes of blast furnace slag were available. Through awareness of environmental considerations and more recently the concept of sustainable development, extensive research and development has transformed slag into modern industrial product which is effective and beneficial.

The American Society of Testing and Materials (ASTM) (1999) defines blast furnace slag as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition at the same time with iron in a blast furnace.” Slag was considered to be essential in the production of iron, but once it served its purpose in refining the metal, it was strictly a nuisance with little or no use. The usefulness of slags was realized with the first ore smelting process. The use of slags became a common practice in Europe at the turn of the 19th century, where the incentive to make all possible use of industrial by-products was strong and storage space for by-products was lacking. Shortly after, many markets for slags opened in Europe, the United States, and elsewhere in the world.

1.2 SLAG DEFINED

Slag is a by-product generated during manufacturing of pig iron and steel. It is produced by action of various fluxes upon gangue materials within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop. Primarily, the slag consists of calcium, magnesium, manganese and aluminium silicates in various combinations. The cooling process of slag is responsible mainly for generating different types of slags required for various end-use consumers. Although, the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling.

The blast furnace (BF) is charged with iron ore, fluxing agents (usually limestone and dolomite) and coke as fuel and the reducing agent in the production of iron. The iron ore is a mixture of iron oxides, silica, and alumina. From this and the added fluxing agents, alkaline earth

carbonates, molten slag, and iron are formed. Oxygen in the preheated air blown into the furnace combines with the carbon of the coke to produce the needed heat and carbon monoxide. At the same time, the iron ore is reduced to iron, mainly through the dioxide. The oxides of calcium and magnesium combine with silica and alumina to form slag. The reaction of the carbon monoxide with the iron oxide yields carbon dioxide (CO₂) and metallic iron. The fluxing agents dissociate into calcium and magnesium oxides and carbon dioxide. The oxides of calcium and magnesium combine with silica and alumina to form slag.

Depending on the cooling method, three types of BF slag are produced: air-cooled, expanded, and granulated. Allowing the molten slag to cool slowly in air in an open pit produces the air-cooled slag. Air-cooled blast furnace slag is defined in ASTM standard C-125 (American Society for Testing and Materials, 1999) as “the material resulting from solidification of molten blast furnace slag under atmospheric conditions. Subsequent cooling may be accelerated by application of water to the solidified surface.” The solidified slag has a vesicular structure with closed pores. The rough vesicular texture of slag gives it a greater surface area than smoother aggregates of equal volume and provides an excellent bond with Portland cement, as well as high stability in asphalt mixtures. Expanded slag is formed through controlled rapid cooling of molten slag in water or in water with combination of steam and compressed air. Steam and other gases enhance the porosity and vesicular nature of the slag, resulting in a lightweight aggregate suitable for use in concrete. Quenching the molten slag into glass granules by using high-pressure water jets produces granulated slag.

Quenching prevents the crystallization of minerals constituting the slag composition, thus resulting in a granular, glassy aggregate. This slag is crushed, pulverized, and screened for use in various applications, particularly in cement production, because of its pozzolanic (hydraulic cementations) characteristics. Slags are also co products of steelmaking processes.

Production of steel calls for the removal of excess silicon by mineralization and of carbon by oxidation from pig or crude iron. Steel slag is a hard, dense material somewhat similar to air-cooled iron slag. It contains important amounts of free iron, giving it its high density and hardness, which make it particularly suitable as a road construction aggregate. Slag is transported to processing plants, where it undergoes crushing, grinding, and screening operations to meet various use specifications. Processed slag is either shipped to its buyer for immediate use or, in slack seasons, stored.

1.3 COMPARISON OF SLAG FORMATION PROCESSES

A comparison of the formation process of various slags is shown in the form of flow chart in Fig. 1.1. A summary of the comparative applications of Blast Furnace Iron Slag, Oxygen Steel Slag and Electric Arc Steel Slag is presented in table 1.1.

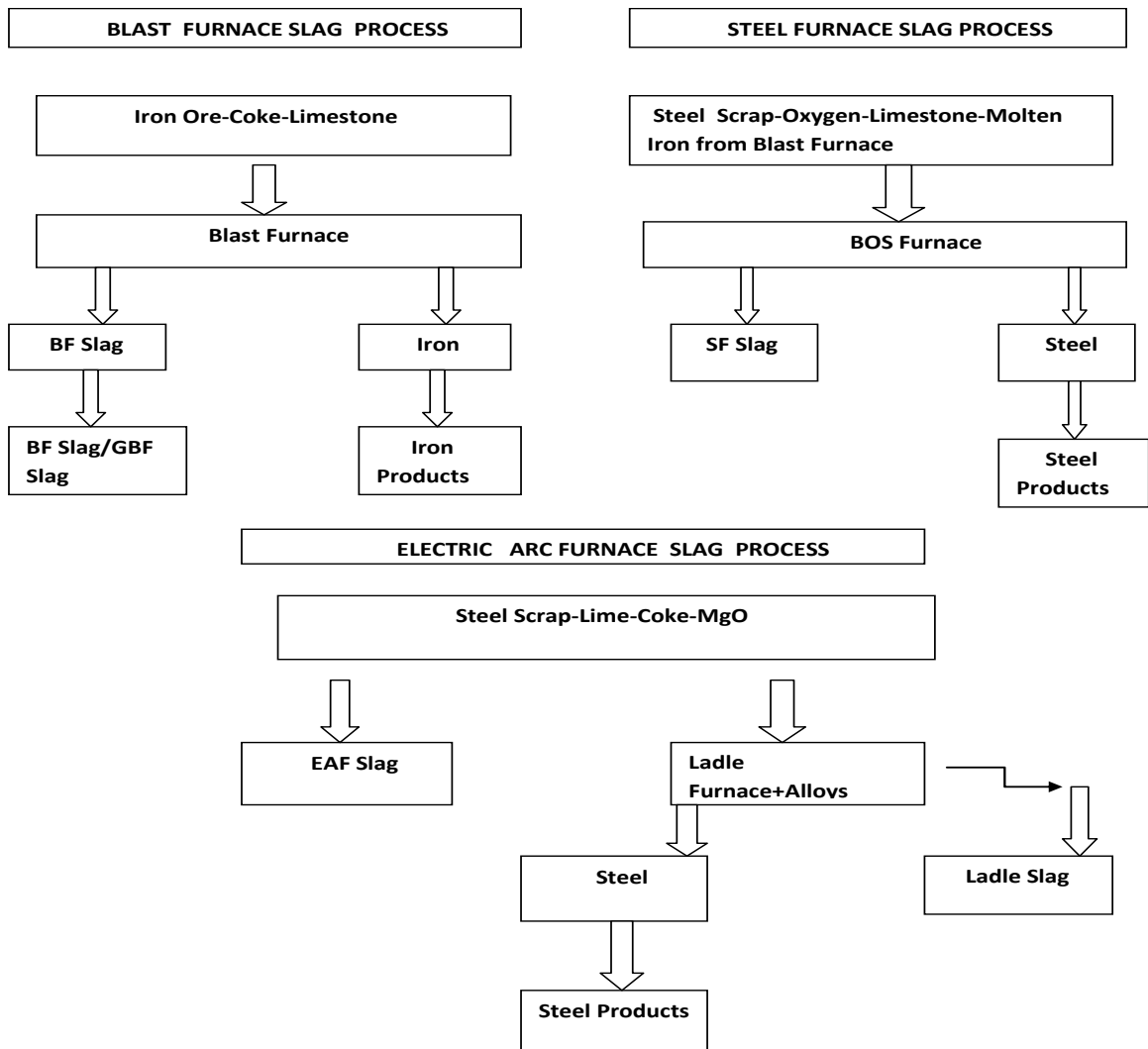


Fig: 1.1 Flow Chart Showing the Processes of Various Slags
(A Guide to the Use of Iron and Steel Slag in Roads. Revision 2, 2002)

Table1.1: Summary of Manufacturing Processes and Applications for Iron and Steel Slag.

(A Guide to the Use of Iron and Steel Slag in Roads. Revision 2, 2002)

| | COMMON NOMENCLATURE | MANUFACTURING PROCESSES | APPLICATION |
|--------------------------------|------------------------------|---|---|
| Blast Furnace Iron Slag | Rock slag or air cooled slag | Crushing and screening slag, slowly air cooled. Also available as uncrushed slag, spalls or skulls. | Base, Sub-base, Concrete aggregate, Filter aggregate, Construction fill and selected fill, Scour Protection, Rockwool |

| | | | |
|---|---|---|---|
| | Granulated slag or slag sand | Rapidly quenching molten slag with high pressure, high volume water sprays. | Sub base, Construction fill Construction sand Stabilizing binder Cement manufacture, Grit blasting, Reinforced earth wall infill, Glass manufacture |
| | Ground Granulated Slag (GGBFS) | Grinding granulated slag to cement fineness. | Cement replacement able to enhance concrete durability and other desirable properties. Stabilizing binder, either alone or blended |
| | Pelletized slag (Not produced in Australia) | Water quenching molten slag on a sloped table and rotating drum, which throws the pellets into the air for further cooling. | Cement manufacture, Lightweight aggregate for concrete and masonry products. |
| | Expanded slag or lightweight slag (Not produced in Australia) | Controlled cooling of slag as a thin layer in a pit followed by crushing and screening. | Lightweight aggregate for masonry products and structural concrete. Skid resistant aggregate. |
| Basic Oxygen Steel Slag BOS slag | BOS slag | Crushing and screening slag which has been air cooled and watered | Sealing aggregate (skid resistant), Asphalt aggregate Base, subbase, Construction fill Subsoil drains, Grit blasting |
| Electric Arc Steel Slag | EAF slag | Crushing and screening slag which Crushing and screening slag which. | Sealing aggregate (skid resistant), Asphalt aggregate Base, subbase, Construction fill Subsoil drains, Grit blasting |

1.4 CHEMICAL COMPOSITION OF SLAGS

In current years, growing thoughtfulness of environmental issues in our society has had an impact in improved utilization of slag. United with member companies identifying new opportunities for slag products are further urbanized .The typical chemistry of BFS, BOS and EAF Slags after exact conditioning and weathering are shown in table 1.2.

Table 1.2: Chemical Composition of Slags (*A Guide to the Use of Iron and Steel Slag in Roads. Revision 2, 2002*)

| Constituents as Oxides | Symbol | BFS Slag (%) | BOS Slag (%) | EAF Slag (%) |
|------------------------|--------------------------------|--------------|--------------|--------------|
| Calcium Oxide | CaO | 41 | 40 | 35 |
| Free lime | - | 0 | 0-2 | 0-1 |
| Silicon Oxide | SiO ₂ | 35 | 12 | 14 |
| Iron oxide | Fe ₂ O ₃ | 0.7 | 20 | 29 |
| Magnesium Oxide | MgO | 6.5 | 9 | 7.7 |
| Manganese Oxide | MnO | 0.45 | 5 | 5.7 |
| Aluminum oxide | Al ₂ O ₃ | 14 | 3 | 5.5 |
| Titanium Oxide | TiO ₂ | 1 | 1 | 0.5 |
| Potassium Oxide | K ₂ O | 0.3 | 0.02 | 0.1 |
| Chromium Oxide | Cr ₂ O ₃ | <0.005 | 0.1 | 1 |
| Vanadium Oxide | V ₂ O ₅ | <0.05 | 1.4 | 0.3 |
| Sulphur | S | <0.6 | 0.07 | 0.1 |

1.5 UTILIZATION OF METALLURGICAL SLAGS IN CONSTRUCTION INDUSTRY

Slag is by-product formed in smelting, and other metallurgical and combustion processes from impurities in the metals or ores being treated. During smelting or refining slag floats on the surface of the molten metal, protecting it from oxidation or reduction by the atmosphere and keeping it clean. In iron and steel production slag phases are generated, formed mainly from the addition of mixture of oxides and fluxes and are also composed of reaction products like those resulting from the oxidation of charge materials and the dissolution of refractories. Primary purpose is to refine the liquid metal by removing impurities.

The main slags are classified in various types: ferrous slag, iron slag generated in blast furnace process, steel slags, non-ferrous slag generated by production non-ferrous metals (Cu, Zn, Pb, Ni) boiler slag obtained by coal combustion plants and incineration slags generated by combustion of solid waste.

1.5.1 Ferrous Slag: It refers to the non-metallic molten material created during the production of hot metal and steel. After this material has slowly cooled in the air, it takes the form of artificial crystalline rock. The manner of its formation thus corresponds to that of natural

volcanic rocks such as basalts. Slag can be used in a wide range of applications and is fundamentally different from ash, the residual material from combustion processes.

1.5.2 Steel Slag: It is a hard, dense material somewhat similar to air-cooled iron slag. During the production of steel in BOF and EAF scrap metal, or metalized ore, or both, the carbon and silicon are removed as carbon dioxide, and the remaining oxidized elements are combined with added lime to form steel slag. The composition and properties of steel-making slags depend on the kind of steel-making process and/or on the type of steel. Steel slags are mostly formed in the process of re melting steel scrap in an EAF. This is the so-called black slag

Small amounts of steel slags are also produced in the processes of secondary metallurgy in a vacuum oxygen decarburization furnace. This is the so-called white slag. White slag is also produced in an EAF during the production of non-rusting steels. They differ from one another in terms of chemical and especially mineral composition and consequently in their properties and their possibilities for use.

1.5.3 Non-Ferrous Slag: They are produced during the recovery by smelting and processing of nonferrous metal from natural ores. Also it often contains residual metal, which, in most cases inhibits their use without further processing. Non-ferrous slags are very often used as fine aggregate in the design of bituminous mixes in road construction.

1.6 STATUS ON USE OF SLAG IN DIFFERENT COUNTRIES

Early use of blast furnace slag in the United States was prompted by the desire to make use of material that was considered an expensive waste product. Its use in earnest started in the early 1900s in the construction field, principally for railroad ballast, Portland-cement-concrete aggregate, and aggregates for bituminous and other types of road construction. The National Slag Association carried out a survey of slag shipments in the United States for the first time in 1938. In 1939, the first year for which comprehensive figures of marketed slag are available, 8.3 million metric tons of blast furnace slag valued at \$6.4 million was used. The slag output from blast furnaces in 1947, the first year in which the U.S. Bureau of Mine collected production statistics, reached almost 30 million tons. Most slag was used in highway construction and railroad ballast.

In year 2000, 8.9 million tons of blast furnace slag valued at \$58.3 million and 5.1 million tons of steel slag valued at \$20.1 million were used. Major uses were in road construction, asphaltic concrete aggregate, Portland cement manufacture, and various concrete products. In the early years of slag use, prospective consumers thought that slag was subject to disintegration and corrosion and was brittle. Slag cements also were questioned, and slag wool was believed to

have high sulphur content. Only after years of research and promotion were these objections overcome.

In 2000, the ferrous slag industry enjoyed the benefits of many individual and collective efforts expended in the development of slag markets. A broader market existed for slag, from mineral wool to roofing granules to agriculture. Virtually all of the slag produced by the iron and steel industry throughout the world was used in such applications as asphaltic concrete aggregate, cement extenders, fill, railroad ballast, road bases, and roofing granules.

Slag production in Europe, including Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom increased by approximately 5%. Approximately 26.2 million tons of blast furnace slag was produced. It was estimated that 31% of this was granulated slag. Basic oxygen steel slag production was estimated at 10.1 million tons.

In India, the Tata Group, one of the largest industrial forces in India, operated an integrated steel plant at Jamshedpur, Bihar in India. More than 0.72 million tons of slag per year was granulated. A 1.73-million-ton-per-year cement plant was built in order to utilize this granulated blast furnace slag. The unit of the plant which was to produce 1 million tons of clinker per year and 0.3 million tons per year of Portland cement unit was installed at Sonadih, Madhya Pradesh, and a grinding plant able to produce 1.43 million tons per year of Portland cement was installed at Jojobera, Bihar.

Data on plant wise average generation of slag in 2009-10 and 2010-11 are given in Table-1.1. As per the Report of the Working Group on Cement Industry for the 12th Plan, around 10 million tonnes BF slag is currently generated in the country from iron & steel industry.

1.7 RESEARCH AND DEVELOPMENT

Producers can enhance the production capacity without additional greenhouse gas emissions like carbon dioxide. A new granulator has been developed to cut the energy cost for granulation. This granulator consists of a variable speed rotating cup atomizer to break up the molten slag by centrifugal force and distribute it within a water-cooled cylindrical chamber. The process cools the molten slag rapidly enough to create small granules, thus minimising the need for additional crushing and grinding. Moreover, the new system offers the possibility of considerable energy recycling in the form of hot water or heated air. Texas Industries has developed a process called Chem. Star for cement clinker production. Thus an increased utilisation of granulated slag benefits the Portland cement producers.

The process involves the use of steel slag. In this process, steel slag is fed into the rotary clinker kiln as a part of the raw material mix. Texas Industries Inc. claimed that clinker production could be enhanced by 15% by using this process.

Commonwealth Scientific & Industrial Research Organisation (CSIRO) carried out investigations for value-added method for slag and proved a number of technically viable and commercially interesting applications of slag. The applications include (i) base course and top course for asphalt roads, (ii) anti-skid surfacing for roads on accident prone intersections, (iii) low-strength concrete for footpaths, (iv) controlled low strength fill for backfill required for trench stabilisation and (v) concrete sub-base for rigid pavements.

Table1.3: Plant wise Average Generation of Slag 2009-10 and 2010-11 (In kg/tonne of hot metal) (Indian minerals year book 2011, part II).

| STEEL PLANT | PRODUCTION | |
|---|------------|---------|
| | 2009-10 | 2010-11 |
| Bhilai Steel Plant, Durg, Chhattisgarh. | 395 | 399 |
| Bokaro Steel Plant Bokaro, Jharkhand | 380 | 370-380 |
| Rourkela Steel Plant, Rourkela, Odisha. | NA | NA |
| Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka. | 318 | NA |
| Durgapur Steel Plant, Durgapur, West Bengal. | NA | NA |
| IDCOL Kalinga Iron Works Ltd, Barbil, Odisha. | NA | 380 |
| Tata Steel Ltd, Jamshedpur, Jharkhand. | 279 | 274 |
| Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh. | 310 | 320 |

Environmental Scientists and toxicologists completed an industry wise "Human Health and Ecological Risk Assessment (HERA) which demonstrated that iron & steel slag poses no meaningful threat to human health or environment when used in a variety of residential, agriculture, industrial and construction application. Consequently the metals in the slag matrix are not readily available for uptake by human, other animals or plants, do not bio accumulate in the food web and are not expected to bio concentrate in plant tissue.

Iron & steel slag may be applied safely in aquatic environment, such as rivers, lakes or streams without impacting water quality or aquatic life. The study carried out by an independent nationally renowned chemical laboratory as demonstrated that blast furnace and steel slag does not pose any threat to human or plant life. The study further revealed that the use of slag has very positive environmental benefits. The use of slag in cement manufacturing significantly decrease CO₂ emission and reduce the energy needed to calcine limestone. The use of slag as aggregate reduces the need for virgin material and the energy use and emission produced during the mining, processing and transportation of those material. The Working Group on Cement for 12th Plan has indentified potential areas for R&D in the Plan period. Some of these which could benefit the cause of utilisation of slags in cement industry are - use of steel slag in road construction; use of non-conventional slags from different metallurgical industries in the manufacture of cement; and activated slag cement and tiles/ bricks/ blocks from slag.

The ASA Association annually undertakes an Environmental Monitoring Programme (EMP) to monitor and assess the iron & steel slag (ISS) produced, processed and sold by its members. The programme involves testing slag samples from member sites for their Total Metal (TM) concentration and wherever necessary, undertaking Toxicity Characteristic Leaching Procedure (TCLP) on the sample required and comparing the results against jurisdictional government regulations. The National Slag Association has proved that iron & steel slag pose no threat to human health or to the environment. Iron & steel slags have been extensively tested using certified laboratories following USEPA and American Society for Testing materials (ASTM) procedures.

1.8 USES OF VARIOUS SLAGS

Different types of slags find different uses in the industry. The air-cooled BF slag is crushed, screened and used mainly as road metal and bases, asphalt paving, railway ballast, landfills and concrete aggregate. The expanded or foamed slag binds well with cement and is used mainly as aggregate for lightweight concrete. However, it is not produced by domestic steel plants. Granulated BF slag is used as a pozzolanic material for producing portland slag cement. It is also used for soil conditioning. BF slag is used in making mineral wool for insulation purposes. Steel slag has found use as a barrier material remedy for waste sites where heavy metals tend to leach into the surrounding environment. Steel slag forces the heavy metals to drop out of solution in water runoff because of its high oxide mineral content. Steel slag has been used successfully to treat acidic water discharges from abandoned mines. Slags are useful alternative raw material for clinker production and such use can reduce a cement plant's fuel consumption and overall emission of carbon dioxide per tonne of cement. The granulated slag obtained from various steel plants is dried in slag dryer. The clinker is ground in ball mill with 40-50% dry slag

and 6% gypsum. The resultant product is Portland slag cement. Portland blast furnace slag cement contains up to 60% ground granulated slag from steel production processes. Slag cement has low heat of hydration, low alkali aggregate reaction, high resistance to chlorides and sulphate and it can substitute the use of 43 and 53 grades of ordinary Portland cement. For other consuming sectors like road making, land filling and ballasting, the cooled slag is crushed by machines or broken manually by hammers into smaller pieces and supplied to the various end-use consumers.

1.9 OBJECTIVE OF THE RESEARCH WORK

The objective of the present work is to study the effect of partial replacement of one of the slags viz. Iron slag. It is proposed to partially replace fine aggregates with iron slag and find its effect on the strength characteristics of concrete. Three percentage levels of replacement i.e. 10, 20 and 30 percent are considered for partially replacing sand with iron slag. M20 concrete grade is initially designed without replacement and subsequently sand is partially replaced with iron slag.

CHAPTER- 2

LITERATURE REVIEW

2.1 GENERAL

Slag is used as substitute to previous clinker. The slag otherwise would have been a waste and used as a filler material slag, if used properly, will conserve valuable limestone deposits required for production of cement. Portland Slag Cement (PSC) has advantages of better performance, durability and optimal production cost, besides being eco-friendly. A brief review of the work carried out by various researchers on use of slag in concrete is presented below.

2.2 MECHANICAL PROPERTIES

2.2.1 Compressive Strength

Monshi and Asgarani (1999) producing Portland cement from iron and steel slags after magnetic separation are mixed with limestone of six different compositions. Samples with higher lime saturation factor developed higher C_3S content and better mechanical properties. Blending 10% extra iron slag to a cement composed of 49% iron slag, 43% calcined lime, and 8% steel slag kept the compressive strength of concrete above standard values for type I ordinary Portland cement. From the six different mixtures of limestone, blast-furnace slag, and converter slag, samples M3, M5, and M6 showed relatively good mechanical properties. Cement M3 was blended with 10% iron slag as in the Portland blast furnace cement, and compressive strengths of 140.3, 193.8, 333.3 kg/cm² were obtained after 3, 7, and 28 days, respectively. The bare minimum compressive strength of concrete for type I Portland cement according to ASTM C150-86 for 3, 7, and 28 days are 12, 19, and 28 MPa, respectively (about 120, 190, and 280 kg/cm²).

Rai et al. (2002) investigated the possibility of using high MnO and low MnO metallurgical slags on samples obtained from an alloy plant of Maharashtra. Electros melt Ltd., Chandrapur, India, could be used as a partial replacement for ordinary Portland cement to make Portland slag cements in India. Low MnO granulated slag was used in making blended slag cement with common Portland cement (OPC). Addition of slag lowered the compressive strength of the blended cement as compared to that of OPC used. The results, as seen from Table 2.1, clearly show that by increasing the slag content, there is a fall in compressive strength, yet the 50:50 composition shows 22 MPa and 33 MPa at 7 and 28 days, respectively, of wet curing to conform to IS 455:1989. The rising the slag content beyond 50% causes lowering of the minimum

compressive strength specific in the Indian standard condition. High MnO slags could not be recommended for use in slag cements because of the deleterious effects of high MnO content.

Table 2.1: Compressive strength of blended cements (Rai et al., 2002)

| S. No. | Portland cement: low MnO slag | Compressive strength (Ma)/ wet curing | | |
|--------|----------------------------------|---------------------------------------|--------|---------|
| | | 3 days | 7 days | 28 days |
| 1 | 100:00 | 30.6 | 33.0 | 61.0 |
| 2 | 80:20 | 18.0 | 29.0 | 46.8 |
| 3 | 70:30 | 16.6 | 25.8 | 35.6 |
| 4 | 60:40 | 15.5 | 24.0 | 33.5 |
| 5 | 50:50 | 15.2 | 22.5 | 33.3 |
| 6 | 40:60 | 6.8 | 12.8 | 20.6 |

Binici et al. (2006) studied the effect of the fineness on the compressive strength for blended and plain Portland cement (PPC) was investigated. The grinding time of both clinker and additives were also studied. The result indicated that ground basaltic pumice (GBP) and clinker had lower grind ability compared to ground granulated blast furnace slag (GGBFS). Blended cement had higher strength values, particularly at later ages, compared to PPC for the same Blaine values. It was observed, from the results shown in Table 2.2 that the finer ground blended cement specimens had higher compressive strength, compared to the coarser blended cement and PPC.

**Table 2.2: Compressive strength of PPC and blended cement specimens (MPa)
(Binici et al., 2006)**

| Specimens | Days | | | | |
|------------------|--------|-------|---------|---------|----------|
| | 3 days | 7days | 28 days | 90 days | 180 days |
| A1 | 25.1 | 32.3 | 45.3 | 50.2 | 54.7 |
| A2 | 29.1 | 38.3 | 48.5 | 53.5 | 58.7 |
| A3 | 34.3 | 44.3 | 51.5 | 57.6 | 62.8 |
| Average A | 29.5 | 38.4 | 48.4 | 53.7 | 58.6 |
| B1 | 23.7 | 31.2 | 43.6 | 49.9 | 53.7 |
| B2 | 25.2 | 35.1 | 47.3 | 50.1 | 58.4 |
| B3 | 31.6 | 42.3 | 50.1 | 57 | 63.8 |

| | | | | | |
|------------------|------|------|----|------|------|
| Average B | 26.8 | 36.2 | 47 | 52.3 | 58.6 |
|------------------|------|------|----|------|------|

Bilim et al. (2008) studied artificial neural networks and predicted the compressive strength of ground granulated blast furnace slag concrete. A data set of a laboratory work, in which a total of 45 concretes were produced, was utilized in the ANNs study. The concrete mixture parameters were three different water–cement ratios (0.3, 0.4, and 0.5), three different cement dosages (350, 400, and 450 kg/m³) and four partial slag replacement ratios (20%, 40%, 60%, and 80%). Compressive strengths of moist cured specimens were measured at 3, 7, 28, 90, and 360 days and are tabulated in Table 2.3.

**Table 2.3: Compressive strength of GGBFS concrete for 450 kg/m³ (MPa)
(Bilim et al., 2008)**

| w/c ratio | GGBFS(%) | Age (days) | | | | |
|-------------|----------|------------|------|------|------|-------|
| | | 3 | 7 | 28 | 90 | 360 |
| 0.30 | 0 | 63.8 | 75.7 | 80.3 | 85.7 | 92.8 |
| | 20 | 58.0 | 72.1 | 81.8 | 90.1 | 95.9 |
| | 40 | 49.8 | 66.4 | 83.8 | 91.4 | 96.8 |
| | 60 | 36.8 | 63.2 | 80.6 | 92.5 | 101.3 |
| | 80 | 26.3 | 50.2 | 66.3 | 77.4 | 78.4 |
| 0.40 | 0 | 53.0 | 59.2 | 64.3 | 71.0 | 79.4 |
| | 20 | 45.8 | 60.3 | 73.5 | 82.3 | 86.6 |
| | 40 | 35.9 | 56.3 | 66.4 | 81.0 | 84.6 |
| | 60 | 26.9 | 38.6 | 61.8 | 73.4 | 80.6 |
| | 80 | 22.6 | 36.7 | 46.8 | 54.6 | 58.9 |
| 0.50 | 0 | 25.8 | 36.6 | 48.7 | 50.5 | 60.2 |
| | 20 | 21.3 | 33.2 | 50.4 | 56.2 | 66.7 |
| | 40 | 16.7 | 28.3 | 49.3 | 53.4 | 65.1 |
| | 60 | 13.0 | 20.8 | 39.5 | 49.1 | 57.4 |
| | 80 | 9.0 | 17.5 | 27.7 | 35.0 | 39.6 |

For all slag replacement ratio, strength contribution of slag to concrete is low up to 7 days of age. However, compressive strength of concrete containing slag concrete is higher than that of control normal Portland cement concrete for 20% and 40% replacement ratios at 28 days, three

months and one year. Compressive strength of slag concrete is found to be equivalent to that of control normal Portland concrete for 60% replacement ratio at 28 days and beyond. The data used in the ANN model are arranged in a format of six input parameters that cover the cement, ground granulated blast furnace slag, water, hyper plasticizer, aggregate and age of samples and, an output parameter which is compressive strength of concrete. The results showed that ANN can be an alternative approach for the predicting the compressive strength of ground granulated blast furnace slag concrete using concrete ingredients as input parameters.

Ismail and Hashmi (2008) reported that the waste iron were reused to partially replaced sand at 10%, 15%, and 20% in a concrete mixtures. The tests performed to assess waste-iron concrete quality included slump, fresh density, dry density, compressive strength, and flexural strength tests. This work is functional for 3, 7, 14, and 28 days curing ages for the concrete mixes. The results (Table 2.4) show that the concrete mixes made with waste iron had higher compressive strengths. The compressive strengths of the concrete mixes made of 20% waste-iron aggregate increase by 22.60%, 15.90% and 17.40% for the 3, 7 and 28 days curing periods.

Table 2.4: Increasing (+) or decreasing (-) (%) in compressive strength of waste iron Concrete mixes. (Ismail and Hashmi, 2008)

| % waste iron aggregates | Increasing(+) or decreasing (-) % | | | |
|-------------------------|-----------------------------------|--------|---------|---------|
| | 3 days | 7 days | 14 days | 28 days |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 8.20 | 11.43 | -6.60 | -1.80 |
| 15 | 15.20 | 14.90 | 2.97 | 12.95 |
| 20 | 22.60 | 15.90 | -0.46 | 17.40 |

Muhmood et al. (2009) studied the cementitious and pozzolanic behavior of electric arc furnace steel slag, both as received and treated in detail. Compression strength of the slag blended cements was studied and it was found that substitution of 20% ground granulated blast furnace slag with electric arc furnace steel slag does not decrease the strength beyond 28 days (see Table 2.5). The control cement has a strength of 58.6 MPa compared to 58 MPa for the cement comprising of 20% untreated slag. The substitution of this untreated slag with treated slag exhibits the highest strength, 61 MPa and a potential for further strength increase after 28 days. In the case of cement mix with no blast furnace slag, substitution of 15% clinker with steel slag does not decrease the strength significantly, 64.4 MPa compared to 66.5 MPa for the control cement. Substituting 30% clinker in the cement mix with electric arc furnace slag however results in significant decrease in strength, 53.4 MPa. The strength of treated EAFS mixed cement on the other hand is equal to that of the control up to 7 days and increases to 61 MPa after 28

days, a value higher than the control mix indicating high later stage strength development. In the case of cement mix without any GGBFS addition, the overall compressive strength decreases when compared to the control mix 2 and the decrease is more pronounced for 30% clinker substitution compared to 15% substitution.

Table 2.5: The cementitious properties of EAFS mixed cements were compared with the controls to determine its influence on the physical properties. (Muhmood et al., 2009)

| Composition, wt. % | Contro1 | Mix A | Mix B | Control2 | Mix C | Mix D | Mix E | Mix F |
|--|---------|-------|-------|----------|-------|-------|-------|-------|
| Clinker | 45 | 45 | 45 | 95 | 80 | 65 | 80 | 65 |
| gypsum | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| GGBFS | 50 | 30 | 20 | 0 | 0 | 0 | 0 | 0 |
| EAFS untreated | 0 | 20 | 0 | 0 | 15 | 30 | 0 | 0 |
| EAFS Treated | 0 | 0 | 20 | 0 | 0 | 0 | 15 | 30 |
| Standard consistency, % | 29.5 | 26.5 | 26.5 | 27.5 | 25.5 | 24.7 | 26.3 | 26.5 |
| Setting time, min | | | | | | | | |
| Initial | 120 | 130 | 120 | 70 | 75 | 90 | 95 | 105 |
| Final | 210 | 220 | 210 | 115 | 125 | 140 | 135 | 150 |
| Compressive strength, MPa at 27°C | | | | | | | | |
| 1-Day | 14.1 | 13.8 | 14.1 | 22.4 | 13.7 | 10.6 | 15.3 | 12 |
| 3-Day | 32.2 | 28 | 31 | 40.3 | 30.6 | 25.4 | 35 | 27.8 |
| 7-Day | 47 | 45 | 44.8 | 53.5 | 44.2 | 36.1 | 41.5 | 36.7 |
| 28-Day | 58.6 | 58 | 61 | 66.5 | 63.3 | 53.4 | 64.6 | 51.4 |

Pellegrino and Gaddo (2009) investigated natural aggregates of traditional concrete with Black/Oxidizing Electric Arc Furnace (EAF) slag. The concrete made with EAF slag as aggregate showed good strength characteristics in normal conditions and strength properties of the conglomerate containing EAF slag are totally comparable than those observed for traditional concrete (see Table 2.6). The compressive strength of cubes specimen with traditional and EAF slag aggregates after 7, 28 and 74 days shown in table as below. It is significant to observe that compressive strength stabilizes, after the first 28 days for traditional conglomerate whereas it

continues to improve for the EAF slag one and thus EAF slag conglomerate aging appears to develop on a longer time than traditional conglomerate.

Table 2.6: Compressive strength of average specimens (Pellegrino and Gaddo, 2009)

| Mix type | 7 days | 28 days | 74 days |
|---------------|--------|---------|---------|
| Traditional | 25.3 | 32.5 | 30.4 |
| With EAF slag | 37.2 | 42.3 | 44.4 |

Maslehuddin et al. (2010) conducted a study to evaluate the mechanical properties and durability characteristics of ordinary Portland cement (OPC) and blended cement (silica fume and fly ash) concrete specimens prepared with electric arc furnace dust (EAFD). Concrete specimens were prepared with and without EAFD. In the silica fume cement concrete, silica fume constituted 8% of the total cementitious material while fly ash cement concrete contained 30% fly ash. EAFD was added as 2% replacement of cement in the OPC concrete and 2% replacement of the total cementitious content in the blended cement concretes. Mechanical properties, such as compressive strength, drying shrinkage, initial and final setting time, and slump retention were determined.

Siddique and kaur (2011) studied the properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures. The compressive strength of concrete mixtures decreased with the increase of GGBFS content at normal temperature (27° C) and 350°C. At room temperature (27°C), 28-day compressive strength of concrete containing 20%, 40% and 60% GGBFS was respectively 16.8%, 23.9% and 28.5% lower than the control mixture (34.8 MPa). Fig. 2.1 shows that at 28-days, with 0% GGBFS, the residual compressive strength of concrete at 100 °C dropped by 28.6% as compared to room temperature strength (34. MPa) and with 20% replacement of cement by GGBFS at 28-days, there is decrease in compressive strength by 11.8% at 100°C and then an increase by 8% at 200°C and another increase, by 15.6%, at 350°C, as compared to room temperature strength (28.9 MPa). But at 40% and 60% replacements of cement with GGBFS at 28-days, the relative residual compressive strength did not change significantly with rises in temperature. After 56-days, the residual compressive strength decreased with the increase in temperature at all percentages of GGBFS. At 0% replacement, the residual compressive strength decreased by 21.9%, 29.9% and 16% at 100, 200 and 350 °C, respectively when compared to normal temperature strength (39.8 MPa).

Ameri et al. (2012) used the steel slag from Zob-Ahan steel production factory in concrete. He replaced natural aggregates from the steel slag and performed compressive strength tests on samples containing slag ratios of 0, 25, 50, 75 and 100 % and cement contents of concrete 200, 300 and 350 kg/m³. According to his results, compressive strength improves with the increase

in steel slag ratio up to 25% but after that increasing the steel slag ratio above 25% decreases compressive strength. The maximum compressive strength value occurs at 25% slag ratio.

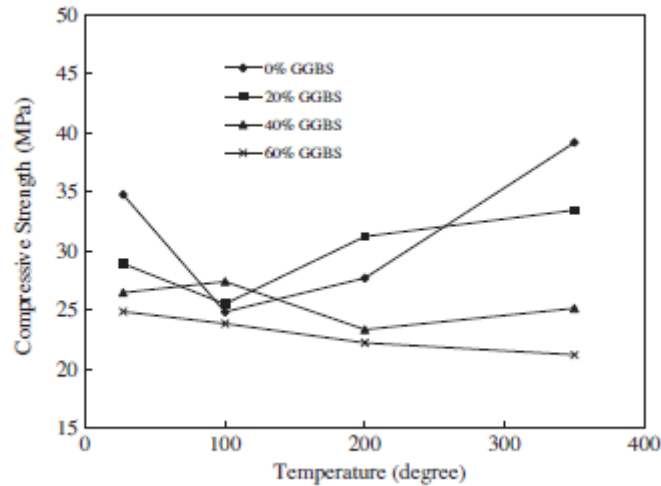


Fig.2.1: Effect of temperature on the compressive strength of concrete at the age of 28 days. (Siddique and kaur, 2011)

Nadeem and Pofale (2012) reported the operation of granular slag as replacement of natural fine comprehensive in construction applications (Masonry & plastering) In this examination cement mortar mixes 1:3, 1:4, 1:5 & 1:6 by volume were selected for 0, 25, 50, 75 & 100% replacements of natural sand with granular slag for w/c ratios of 0.60, 0.65, 0.70 & 0.80 correspondingly. The study gave comparative results for mortar flow behaviours, compressive & split tensile strengths, brick mortar crushing & pulls strengths and their co-relations. The study comprises of the experimental results obtained show that partial substitution of ordinary sand by slag gives better results in both the applications i.e. masonry & plastering. The sand replacement from 50 to 75% improved mortar flow properties by 7%, the compressive strength improved by 11 to 15 % for the replacement level from 25 to 75%. At the same time brick mortar crushing & pull strengths improved by 10 to 13% at 50 to 75% replacement levels. The co-relation between mortar compressive/split tensile strengths & brick crushing/pull strengths shows linear dependency on each others.

2.2.2 Split Tensile Strength

Aldea et al. (2000) studied the effects of curing conditions on properties of concrete by partial replacement of slag. He replaced 0% slag (control), 25% slag, 50% slag, and 75% slag with the cement. The specimen size 75 × 75 mm was used according to ASTM C 496-90. There is small effect of slag replacement up to 50% upon strength, whereas higher replacement results in a fall in compressive strength. The 25% and 50% slag replacement have a valuable effect compared to control, as tensile strength increases for all the curing types. The 50% slag replacement

provides tensile strength to some extent higher to no slag replacement, whereas the 75% slag replacement reduces the tensile strength regardless of the curing type used.

Maslehuddin *et al.* (2002) studied the properties of steel slag and crushed limestone aggregate concretes. He observed that the physical properties of steel slag aggregate concrete were better than those of crushed limestone aggregate concrete (see Table 2.7). The mix design for parameters for steel slag and limestone aggregate cement concretes were 400 kg/m³ and w/c ratio was 0.40 for both. The maximum aggregates size was 12.5 mm for both and coarse to total aggregate ratio for limestone concrete was 0.60 and for steel slag concrete were varies as 0.45,0.50,0.55,0.60 and 0.65. The split tensile strength of the steel slag aggregate concrete also increased with the ratio of coarse aggregate. The split tensile strength of the crushed limestone aggregate concrete was 6.33 MPa while it was in the range of 5.79 to 6.35 in the steel slag aggregate concretes. The split tensile strength of the steel slag aggregate concrete was less than that of crushed limestone aggregate concrete when the proportion of coarse aggregate was less than 65%.

Table2.7: Strength (MPa) of concrete specimens prepared using crushed limestone and varying percent of steel slag aggregate. (Maslehuddin et al., 2002)

| Test | Crushed limestone aggregate (60%) | Steel slag aggregate | | | | |
|------------------------|-----------------------------------|----------------------|------|------|------|------|
| | | 45% | 50% | 55% | 60% | 65% |
| Compressive strength | 39.7 | 31.4 | 37.7 | 37.6 | 41.6 | 42.7 |
| Split tensile strength | 6.33 | 5.79 | 6.06 | 6.11 | 6.26 | 6.35 |

Yigiter *et al.* (2006) studied the properties of slag cement and Portland cement for different water/cement ratio cement content on sea water resistance of concrete. He indicate that blast furnace slag cement (SC) mixtures have much greater resistance to sea water than portland cement (PC) mixtures both from the point of mechanical properties. The concrete mixtures were prepared with two different cements (PC, SC) with three different W/C ratios by weight (0.43, 0.53, 0.63) and three different cement contents (250, 350, 450 kg/m³) tested for 28 and 90 days. On the other hand, the increase in W/C ratio decreases the compressive strength and tensile strength of the mixtures at all cement contents except 250 kg/m³ PC mix. At this mix, the increase in W/C ratio from 0.43 to 0.53 resulted in slight increase in strength. This is probably due to the workability problems at a W/C ratio of 0.43.

Nazar and Riahi (2010) studied the split tensile strength together with pore structure, thermal behavior and microstructure of concrete containing ground granulated blast furnace slag and SiO₂ nanoparticles have been investigated. Portland cement was replaced by different amounts of ground granulated blast furnace slag and the properties of concrete specimens were measured. Although it negatively impacts the properties of concrete at early ages, ground granulated blast furnace slag was found to improve the physical and mechanical properties of concrete up to 45 wt% at later ages. SiO₂ nanoparticles with the average particle size of 15nm were partially added to concrete with the optimum content of ground granulated blast furnace slag and physical and mechanical properties of the specimens were studied. SiO₂ nanoparticle as a partial replacement of cement up to 3 wt% could accelerate C-S-H gel formation as a result of increased crystalline Ca(OH)₂ amount at the early age of hydration and hence increase split tensile strength of concrete specimens. The increased the SiO₂ nanoparticles' content more than 3 wt% causes the reduced the split tensile strength because of the decreased crystalline Ca(OH)₂ content required for C-S-H gel formation. SiO₂ nanoparticles could improve the pore structure of concrete and shift the distributed pores to harmless and few-harm pores.

2.3 DURABILITY CHARACTERISTICS

2.3.1 Sulphate Resistance

Bakharev et al. (2001) investigated the durability of alkali-activated slag (AAS) concrete in sulfate environment. He conducted two tests to find out resistance of alkali-activated slag (AAS) concrete to sulphate attack. These tests involved immersion in 5% magnesium sulphate and 5% sodium sulphate solutions. He observed that the strength decrease was up to 17% for alkali-activated slag (AAS) concrete and up to 25% for ordinary Portland cement (OPC) concrete after 12 months exposure to sodium sulphate solution. After the same time of exposure to the magnesium sulphate solution, the compressive strength decrease was more up to 37% for OPC and 23% for alkali-activated slag (AAS). The Visual examination of OPC concrete shows expansion, cracking, and loss of concrete at the corners of OPC concrete specimens immersed in MgSO₄ solution (Fig. 2.2). OPC concrete experienced larger expansion in sodium sulphate than in magnesium sulphate solution, but the cracking and loss of concrete was more significant in the magnesium sulphate solution. The compressive strength reduction up to 60 days, was the same for AAS and OPC concretes in both environments. Later than, the strength reduction in OPC was higher than that in AAS samples in both environments.



**Fig.2.2: OPC sodium concrete cylinders exposed to sulfate solution for 12 months.
(Bakharev et al., 2001)**

Higgins (2003) studied the addition of a small percentage of calcium carbonate or calcium sulfate, affects the sulfate resistance of concrete containing ground granulated blast furnace slag (GGBS). He immersed in magnesium and sodium sulphate solutions and their expansions monitored for up to six years. He found that both calcium carbonate and calcium sulfate additions, had a regular beneficial effect on the resistance of GGBS concrete to conventional sulfate attack, both in respect to expansion and in respect of disintegration. Table 2.8 shows the compressive strength of the cubes stored in water and in the sulfate solutions. In sodium sulfate solution, the PC-only concrete had almost completely disintegrated by 6 years, while the GGBS concretes were generally showing only minor strength- and corner-loss. As would be expected, 70% GGBS was more resistant to attack than 60% GGBS. The lower level of addition of calcium sulphate significantly increased the degree of attack. On the other hand at the higher level of addition of calcium sulphate, the degree of attack was reduced, as was also the case with the addition of calcium carbonate. In magnesium sulfate solution, the PC-only concrete performed to some extent better, whereas the GGBS concretes performed noticeably less well in the magnesium than the sodium solution. This is what is normally observed with GGBS concrete usually more susceptible to attack by magnesium sulfate than sodium sulfate. Once again 70% GGBS is more resistant than 60% and the lower level of addition of calcium sulfate gave no advantage. The higher level of addition of calcium sulfate and the addition of calcium carbonate both reduced the degree of attack.

Table 2.8: Compressive strength in water and in sulfate solutions (Higgins, 2003)

| Compressive strength in water (N/mm ²) | | | | | | | % strength in Na ₂ SO ₄ | | | % strength in MgSO ₄ | | |
|--|-------|-------|--------|--------|---------|---------|---|---------|---------|---------------------------------|---------|---------|
| | 3-day | 7-day | 28-day | 1-year | 2-years | 6-years | 1-year | 2-years | 6-years | 1-year | 2-years | 6-years |
| Portland cement | 34 | 41 | 53 | 66 | 68 | 69 | 97 | 87 | 0 | 85 | 74 | 28 |
| 60% GGBS | 17 | 31 | 48 | 65 | 69 | 73 | 106 | 97 | 62 | 95 | 75 | 18 |
| 70% GGBS | 13 | 28 | 49 | 63 | 66 | 71 | 105 | 89 | 90 | 94 | 77 | 28 |
| 60% GGBS +LS | 15 | 28 | 45 | 67 | 69 | 76 | 99 | 97 | 84 | 96 | 83 | 41 |
| 60% GGBS + 2% SO ₂ | 19 | 29 | 47 | 68 | 67 | 72 | 97 | 99 | 33 | 94 | 81 | 19 |
| 60% GGBS + 3% SO ₃ | 18 | 32 | 50 | 62 | 69 | 75 | 102 | 99 | 80 | 94 | 88 | 50 |

Al-Akhras (2006) studied the consequence of metakaolin (MK) substitute of cement on the durability of concrete to sulphate attack. The three metakaolin replacement levels were considered in the study ie 5%, 10%, and 15% by weight of cement. The study showed that metakaolin replacement of cement increased the sulphate resistance of concrete. The sulphate resistance of metakaolin concrete improved with increasing the metakaolin substitution level. Concrete containing 10% and 15% metakaolin replacement showed tremendous durability to sulphate attack. The first cracks of plain and metakaolin concrete specimens due to sulphate attack start to come out on the corners of concrete specimens. Subsequently, cracking and spalling were propagated through the surface of the specimens. First, the replacement of a portion of Portland cement with metakaolin reduces the total amount of tricalcium aluminate hydrate in the cement paste matrix of concrete. Also, the formation of secondary C-S-H by the pozzolanic reaction, even if less thick than the primary C-S-H gel, is effective in filling and segmenting large capillary pores into small, irregular capillary pores through pore size refinement.

Binici et al. (2006) studied the effect of the fineness on the sodium sulfate resistance for blended and plain Portland cement (PPC). It was observed that the finer ground blended cement

specimens had higher sodium sulfate resistance compared to the coarser blended cement and PPC. These results (Table 2.9) show that there was an obvious increase in the sulphate resistance of the mortars with an increase in fineness of cement. For PPC mortars, the relative compressive strength decreases rapidly and disperses after 36 months, whereas, A3, B2 and B3 blended cement mortars preserved their integrity for 36 months. Blended cement B3 exhibited greater sulphate resistance than any of the other specimens, as shown in table. Compressive strength of the specimens increased when they were immersed in sodium sulphate solution for 12 months. The amount of increase in A1, A2, A3 and B1, B2, B3 specimens was 6.2%, 14%, 13.1% and 1.6%, 6.3% and 7.2%, respectively. From these values, the increase in the compressive strength of the control specimens was more than that of the blended cement specimens at the end of 12 months duration in sodium sulphate solution. Also, the compressive strength of the specimens with high fineness was higher than that of the specimens with low fineness. The compressive strength of the control specimens A1, A2, and A3 was lower than 28 days compressive strength values about 48.1%, 14% and 8.4%, respectively when they were immersed in sodium sulphate solution for 24 months. Similarly, the compressive strength of the blended cement specimens B1, B2 and B3 was lower than 28 days compressive strength values about 22.7%, 7.2% and 2.3%, respectively when they were immersed in sodium sulphate solution for 24 months. These values showed that when the fineness increased, the resistance to the sodium sulphate solution also increased. Furthermore, sodium sulphate resistance of the blended cement specimens was higher than that of the control specimens. The specimens A1, A2 and B1 were completely disintegrated when they were immersed in sodium sulphate solution for 36 months.

**Table 2.9: The sodium sulfate resistance of PPC and blended cement specimens (MPa)
(Binici et al., 2006)**

| Specimens No. | For 28 days in pure water | For 12 months | For 24 months | For 36 months |
|----------------------|----------------------------------|----------------------|----------------------|----------------------|
| A1 | 45.3 | 48.1 | 23.5 | Dispersed |
| A2 | 48.5 | 55.3 | 41.7 | Dispersed |
| A3 | 51.1 | 57.8 | 46.8 | 27.4 |
| Average A | 48.3 | 53.7 | 37.3 | |
| B1 | 43.6 | 44.3 | 33.7 | Dispersed |
| B2 | 47.3 | 50.2 | 43.9 | 27.8 |
| B3 | 50.1 | 53.7 | 48.9 | 35.9 |
| Average B | 47 | 49.4 | 42.1 | |

Mingyu et al. (2006) studied the sulphate attack in concrete of Yongan Dam in China. According to investigations, it is shown that the concrete of Yongan Dam is deteriorated due to the thaumasite form of sulphate attack (TSA). According to the results of micro analytical investigations and inspection of the deteriorating element, it is likely that the thaumasite in Yongan Dam concrete can be formed both by the routes of solution reaction and ettringite conversion. On the one hand, the Ca(OH)_2 in concrete reacts with SO_4 to produce gypsum which reacts with CaCO_3 and CSH to form thaumasite. On the other hand, due to the C_3A -content of the Portland cement, formation of secondary ettringite was possible. This could be yielded in expansions and deterioration of the concrete structure.

Rozière et al. (2009) studied the durability of concrete exposed to sulphate attacks for the mortar and concrete samples. The mass of control and attacked specimens of concrete was checked. The control specimens stored in tap water showed a slight mass increase, which corresponds to hydration, but specimens stored in sulphate solution showed much lower swell or minor loss of mass. The expansion and cracking have been seen in the concrete samples when exposed to sodium sulphate solution with high sulphate concentration, i.e. equal to 20 g/L or higher. For the mortar samples, three control specimens were vacuum soaked with tap water and immersed in water and three others specimens were saturated with sodium sulphate solution and immersed in the solution. The sulphate concentration is 30 g/L. The solution was prepared using demineralised water and renewed once a month. The expansion was seen before cracking by the monitoring of length. After immersion in solution, water and hydration are likely to occur. There is increase in mass due to swelling caused by gypsum and ettringite formation in damaged mortar specimens.

Ogawa et al. (2011) reported the improvement on sulphate resistance of blended cement with high alumina slag. He focused on the effect of limestone and calcium sulphate content on sulphate resistance of ground granulated blast furnace slag (GGBS) blended cement. In GGBS, the alumina tends to form ettringite with externally complete sulphate ions. Addition of limestone and increase in calcium sulphate content allow both monocarboaluminate and ettringite to form prior to immersion in sulphate solution. These hydration products remain in the hardened cement matrix and act to contain further development of ettringite with external sulphate ions during immersion in sulphate solution. GGBS blended cement with a suitable amount of limestone powder and a controlled content of calcium sulphate exhibits clearly long term sulphate resistance. The use of high-alumina GGBS did not effectively improve Sulphate resistance without sufficient calcium sulphate content and limestone in the cement. Addition of limestone powder (4% or 8%) in GGBS blended cement (OPC, 30 to 40% replacement of improved sulphate resistance, because of formation of mono carboaluminate and decrease in monosulfate that tend to form expansive ettringite with external sulfate ions on the other hand,

improvement of sulphate resistance by limestone addition through this mechanism was limited, because it was possible that monocarboaluminate transformed slowly to ettringite with the supply of external sulfate ions. In GGBS blended cement the increase in calcium sulphate content improved sulphate resistance, because sufficient calcium sulphate increased retention of firstly formed ettringite, and then diminishing the potential for monosulphate reaction with external sulphate ions.

Veiga and Gastaldini (2012) studied the sulfate resistance of a white Portland cement (WPC) containing 0%, 50% or 70% granulated blast-furnace slag as a partial cement replacement. The piece of the blended cements was monitored by exposing the prepared mortar specimens to a 5% Na₂SO₄ solution for two years according to ASTM C1012/04. He observed that the slag in the partial cement replacement benefits in both cements and an increase in its percentage increased sulfate resistance. For long-term exposure, all of the WPC blends showed a smaller amount of expansion than the corresponding blends with PC. After 24 months of exposure to a sodium sulfate solution, WPC established higher resistance to sodium sulfate attack than grey Portland cement and this was maybe due to the lower CH content of the WPC hydrated paste. When the slag replacement level was higher, the expansion values were lower in ASTM C1012 test due to dilution effect and pozzolanic reactions that consume CH and density the matrix. All of the mortar mixtures containing white Portland cement exhibited enhanced resistance to sulfate attack than the corresponding grey Portland cement mortars. There could have been a balancing effect between the slag and the limestone used as filler in the WPC.

3.1 GENERAL

The present chapter deals with the presentation of results obtained from various tests conducted on material used for the concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of iron slag on compressive strength, split tensile strength and sulphate resistance of concrete.

3.2 MATERIALS

The properties of material used for making concrete mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were cement, coarse aggregates, fine aggregates, in addition to iron slag. The aim of studying of various properties of material is used to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular strength. The description of various materials which were used in this study is given below:

3.2.1 Portland Cement

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the total volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cement offers many advantages for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% saving in cement consumption and also they offer many hidden benefits. One of the most important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) of 43 Grade (JK cement) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of

the cement as determined from various tests conforming to Indian Standard IS: 8112:1989 are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength. The results of above said tests are given below in Table 3.1.

Table 3.1 Properties of OPC 43 Grade Concrete

| Sr. No. | Characteristics | Values Obtained Experimentally | Values Specified By IS 8112:1989 |
|---------|-------------------------------|--------------------------------|----------------------------------|
| 1. | Specific Gravity | 3.12 | - |
| 2. | Standard Consistency, percent | 29 | - |
| 3. | Initial Setting Time, minutes | 147 | 30 (minimum) |
| 4. | Final Setting Time, minutes | 305 | 600 (maximum) |
| 5. | Compressive Strength | | |
| | 3 days | 24.8 N/mm ² | 23 N/mm ² (minimum) |
| | 7 days | 37.5 N/mm ² | 33 N/mm ² (minimum) |
| | 28 days | 47.6 N/mm ² | 43 N/mm ² (minimum) |

It can be observed from tables that all the results satisfy the standard criteria.

3.2.2 Aggregates

Aggregates constitute the bulk of a concrete mixture and give dimensional stability to concrete. To increase the density of resulting mix, the aggregates are frequently used in two or more sizes. The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assist the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the possible segregation of paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to placement. The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean, hard, strong and well graded.

a) Coarse Aggregates: The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types:-

- i) Crushed graves or stone obtained by crushing of gravel or hard stone.

- ii) Uncrushed gravel or stone resulting from the natural disintegration of rocks.
- iii) Partially crushed gravel obtained as product of blending of above two types.

The normal maximum size is gradually 10-20 mm; however particle sizes up to 40 mm or more have been used in Self Compacting Concrete. Gap graded aggregates are frequently better than those continuously graded, which might expensive grader internal friction and give reduced flow. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of interlocking of angular particles, while rounded aggregates improved the flow because of lower internal friction.

Locally available coarse aggregate having the maximum size of 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. Specific gravity and other properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done. Table 3.3 show the result of sieve analysis. Proportioning of coarse aggregates was done and fineness modulus was obtained.

Table 3.2 Properties of Coarse Aggregates

| Characteristics | Value |
|------------------|---------|
| Colour | Grey |
| Shape | Angular |
| Maximum Size | 20 mm |
| Specific Gravity | 2.69 |

Table 3.3 Sieve Analysis of Coarse Aggregate (20 mm)

| <i>Weight of sample taken = 3000gm</i> | | | | | |
|--|---------------|-------------------|---------------|--------------|-----------------------|
| Sr. No | IS-Sieve (mm) | Wt. Retained (gm) | %age retained | %age passing | Cumulative % retained |
| 1 | 80 | 0.00 | 0.00 | 100.00 | 0.00 |
| 2 | 40 | 0.00 | 0.00 | 100.00 | 0.00 |
| 3 | 20 | 68.5 | 2.28 | 97.72 | 2.28 |
| 4 | 10 | 2776.5 | 92.55 | 5.17 | 94.83 |
| 5 | 4.75 | 113.5 | 3.78 | 1.38 | 98.62 |
| 6 | Pan | 0.00 | 0.00 | 0.00 | |
| | Total | 3000.00 | | SUM | 195.73 + 500 = |
| | | | | <i>FM =</i> | <i>6.95</i> |

b) Fine Aggregates: The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:

- i) Natural sand, i.e. fine aggregate resulting from natural disintegration of rocks.
- ii) Crushed stone sand, i.e. fine aggregate produced by crushing hard stone.
- iii) Crushed gravel sand, i.e. fine aggregate produced by crushing natural gravel.

According to size, the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV.

In this experimental program, fine aggregate was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and conforming to grading zone II. It was coarse sand light brown in colour. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are shown in Table 3.4 and Table 3.5.

Table 3.4 Physical Properties of fine aggregates

| Characteristics | Value |
|----------------------------------|-------|
| Specific gravity | 2.59 |
| Bulk density(kg/m ³) | 1.3 |
| Fineness modulus | 2.62 |
| Water absorption, % | 0.89 |

Table 3.5 Sieve Analysis of Fine Aggregate

| <i>Weight of sample taken =1000 gm.</i> | | | | | |
|---|---------------|-------------------|---------------|--------------|-----------------------|
| Sr. No. | IS-Sieve (mm) | Wt. Retained (gm) | %age retained | %age passing | Cumulative % retained |
| 1 | 4.75 | 14.5 | 1.45 | 98.55 | 1.45 |
| 2 | 2.36 | 37 | 3.70 | 94.85 | 5.15 |
| 3 | 1.18 | 246.5 | 24.65 | 70.20 | 29.80 |
| 4 | 600 μ | 205.5 | 20.55 | 49.65 | 50.35 |
| 5 | 300 μ | 287.5 | 28.75 | 20.90 | 79.10 |
| 6 | 150 μ | 177 | 17.70 | 3.20 | 96.80 |
| 7 | Pan | 32 | 3.20 | | |
| | Total | 1000.00 | | SUM | 262.65 |
| | | | | <i>FM =</i> | <i>2.62</i> |

3.2.3 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

3.2.4 Iron Slag

In this work, the Iron Slag is taken from the Dhiman Iron and Steel industry located at Mandi Gobindgarh, Punjab. It is black in colour as shown in figure. The sieve analysis of iron slag is shown in Table 3.6.



Fig. 3.1: concrete mix with iron slag

3.2.5 Magnesium Sulphate

The Powder form of Magnesium Sulphate was obtained from Swindra Instruments Corporation, Anand Pura, Patiala. It was white in color. The solution of strength 50g/l as per ASTM C1012 was made by adding it to water and used for sulphate resistance test.

Table 3.6 Sieve Analysis of iron slag

| <i>Weight of sample taken =1000 gm.</i> | | | | | |
|---|----------------------|--------------------------|----------------------|---------------------|------------------------------|
| Sr. No. | IS-Sieve (mm) | Wt. Retained (gm) | %age retained | %age passing | Cumulative % retained |
| 1 | 4.75 | 14 | 1.4 | 98.6 | 1.4 |
| 2 | 2.36 | 28 | 2.8 | 95.8 | 4.2 |
| 3 | 1.18 | 94.5 | 9.45 | 86.35 | 13.65 |
| 4 | 600 μ | 189.5 | 18.45 | 67.8 | 32.1 |
| 5 | 300 μ | 329.5 | 32.95 | 34.95 | 65.05 |
| 6 | 150 μ | 291.5 | 29.15 | 5.8 | 94.2 |
| 7 | Pan | 58 | 5.8 | | |
| | Total | 1000.00 | | SUM | 210.6 |
| | | | | <i>FM =</i> | <i>2.10</i> |



Fig. 3.2: Magnesium Sulphate

3.3 TEST METHODS

The procedure of methods used for testing cement, coarse aggregates, fine aggregate and concrete are given below:

3.3.1 Specific Gravity

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

3.3.2 Sieve Analysis for Coarse and Fine Aggregates as per IS: 2386 (Part I) – 1963

The sieve analysis is used for the determination of particle size distribution of fine and coarse aggregates by sieving or screening.

3.3.3 Compressive Strength of Concrete:

Cube specimens of size 150 mm x 150 mm x 150 mm were taken out from the curing tank at the ages of 7, 28 and 56 days and tested immediately on removal from the water (while they were still in the wet condition). Surface water was wiped off, the specimens were tested. The position of cube when tested was at right angle to that as cast. The load was applied gradually without shock till the failure of the specimen occurs and thus the compressive strength was found.

The quantities of cement, coarse aggregate (20 mm), fine aggregate, iron slag and water for each batch i.e. for different percentage of iron slag replacement was weighed separately. The cement and iron slag were mixed dry to a uniform colour separately. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Then the concrete was filled into the cube moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.3.4 Split Tensile Strength of Concrete:

The split tensile strength of concrete is determined by casting cylinders of size 150 mm X 300 mm. The cylinders were tested by placing them uniformly. Specimens were taken out from curing tank at age of 7, 28 and 56 days of moist curing and tested after surface water dipped down from specimens. This test was performed on Universal Testing Machine (UTM). The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading is given by formula

$$T = 0.637P/dl$$

Where,

T = Split Tensile Strength in MPa

P = Applied load,

D = Diameter of Concrete cylinder sample in mm.

L = Length of Concrete cylinder sample in mm.

The quantities of cement, coarse aggregate (20 mm), fine aggregate, iron slag and water for each batch i.e. for different percentage of iron slag replacement was weighed separately. The cement and iron slag were mixed dry to a uniform colour separately. Fine aggregate was mixed to this mixture in dry form. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Then the concrete was filled into the cylindrical moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.3.5 Sulphate Resistance Test

Tests performed for checking the sulphate resistance of concrete, produced using iron slag as partial replacement for sand, in this work are compressive strength test after immersing the cube specimen in 50g/l of magnesium sulphate solution(as per per ASTM C1012) for 7, 28 and 56 days. Before immersing them in sulphate solution, specimens are cured for 28 days in water under normal temperature.

Cube specimens of size 150 mm x 150 mm x 150 mm were taken out from the magnesium sulphate solution at the ages of 7, 28 and 56 days and tested immediately on removal from the solution (while they were still in the wet condition). Surface solution was wiped off before testing the specimens for compressive strength. The position of cube when tested was at right angle to that as cast. The load was applied gradually without shock till the failure of the specimen occurs and thus the compressive strength was found.

3.4 X-RAY DIFFRACTION

X-ray diffraction is one of the most powerful tools for identifying unknown crystalline phases. By comparing the positions and intensities of the diffraction peaks against a library of known crystalline materials, the target material can be recognized. In addition, multiple phases in a sample can be identified and quantified. Even if one of the phases is amorphous, x-ray diffraction can find out the relative amount of every phase.

3.4.1 Samples Testing

In carrying out the X-ray diffraction, the concrete samples are first grinded into powder form. The sample size is normally 0.002mm to 0.005 mm and then they are put into the small packets. X-ray diffraction (XRD) data for grind samples were tested on Panalytical's X'Pert Pro with Cu

K α radiation at IIT Ropar, Punjab. The samples are scanned in the range of $2\theta = 5 - 60^\circ$ at the scanning speed of $2^\circ/\text{min}$.



Fig .3.3: Panalytical's X'Per

3.5 MIX DESIGN (M20)

A) Test data for materials

| | | |
|-------|---------------------------------------|-------|
| (i) | Specific gravity of cement | 3.12 |
| (ii) | Specific gravity of coarse aggregates | 2.69 |
| (iii) | Specific gravity of fine aggregates | 2.54 |
| (iv) | Zone of fine aggregates | II |
| (v) | Water absorption of coarse aggregates | 0.43% |
| (vi) | Water absorption of fine aggregates | 0.89% |

The mix proportions obtained for the various mixes cast are tabulated in Table 3.7

Table 3.7 Proportions of Concrete Mixtures

| Mix Designation | Water (W) kg/m³ | Cement (C) kg/m³ | Fine Aggregates(FA) kg/m³ | Iron Slag (IS) kg/m³ | Coarse Aggregates (CA) kg/m³ | Ratio of W:C:FA:IS:CA |
|------------------------|-----------------------------------|------------------------------------|---|--|--|------------------------------|
| M20 | 180 | 360 | 573.86 | 0.00 | 1233.54 | 0.5:1:1.59:0:3.42 |
| M20 | 180 | 360 | 516.48 | 57.38 | 1233.54 | 0.5:1:1.43:0.15:3.42 |
| M20 | 180 | 360 | 459.088 | 114.772 | 1233.54 | 0.5:1:1.27:0.31:3.42 |
| M20 | 180 | 360 | 401.702 | 172.158 | 1233.54 | 0.5:1:1.11:0.47:3.42 |

CHAPTER-4

RESULTS AND DISCUSSION

4.1 GENERAL

This chapter deals with the presentation of results obtained from various tests conducted on concrete specimens cast with and without iron slag. The main objective of the research program was to understand the strength and durability aspects of concrete obtained using iron slag as partial replacement for sand. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of iron slag on compressive strength, split tensile strength and sulphate resistance of concrete. The experimental program consists of casting, curing and testing of controlled and iron slag concrete specimen at different ages.

The experimental program included the following:

- Testing of properties of materials used for making concrete.
- Design mix (M20).
- Casting and curing of specimens.
- Tests to determine the compressive strength and split tensile strength and sulphate resistance of concrete.

4.2 COMPRESSIVE STRENGTH

4.2.1 General

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 crack occurs 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 the lateral tensile strains.

4.2.2 Test Procedure and Results

Test specimens of size 150 × 150 × 150 mm were prepared for testing the compressive strength concrete. The concrete mixes with varying percentages (0%, 10%, 20% and 30%) of iron slag as partial replacement of fine aggregate (sand) were cast into cubes and cylinders for subsequent testing.

In this study, to make concrete, cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine

aggregates. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of $27^{\circ} \pm 2^{\circ}\text{C}$. The specimens so cast were tested after 7, 28 and 56 days of curing measured from the time water is added to the dry mix. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Results of the compressive strength test on concrete with varying proportions of iron slag replacement at the age of 7, 28 and 56 days are given in the Table 4.1.

Table 4.1: Compressive strength of concrete mixes of specimen size $150 \times 150 \times 150$ with iron slag

| Mix | Compressive Strength (N/mm ²) | | | Average Compressive Strength (N/mm ²) | | |
|-----|---|---------|---------|---|---------|---------|
| | 7 days | 28 days | 56 days | 7 days | 28 days | 56 days |
| CM | 20.58 | 25.79 | 32.55 | 19.75 | 26.09 | 32.05 |
| | 20.54 | 26.12 | 33.87 | | | |
| | 18.13 | 26.36 | 29.74 | | | |
| 10% | 27.7 | 37.88 | 45.87 | 25.02 | 39.33 | 46.06 |
| | 24.25 | 39.68 | 45.06 | | | |
| | 23.13 | 40.44 | 46.60 | | | |
| 20% | 35.21 | 51.86 | 59.15 | 33.52 | 49.90 | 57.07 |
| | 31.65 | 49.55 | 54.31 | | | |
| | 33.71 | 48.31 | 57.77 | | | |
| 30% | 45.15 | 56.40 | 57.55 | 44.44 | 55.68 | 60.21 |
| | 41.84 | 57.37 | 62.13 | | | |
| | 46.35 | 53.28 | 60.97 | | | |

The cube strength results of concrete mix are also shown graphically in Figure 4.1. The compressive strength increases as compared to control mix as the percentage of iron slag is increased. After adding 10% iron slag in the mix, there is an increase of 26% after

7 days, 50% increase after 28 days and 43% increase after 56 days as compared to the control mix. By adding 20% and 30% iron slag, there is large amount of increase in percentage i.e. 68%, 91%, 78% and 125%, 113%, 87% after 7, 28 and 56 days respectively.

Figure 4.2 shows the variation of percentage increase in compressive strength with replacement percentage of iron slag. The results also indicate that early age strength gain i.e. at 7 and 28 days, is higher when compared to the control mix if 30% of fine aggregate is replaced by iron slag.

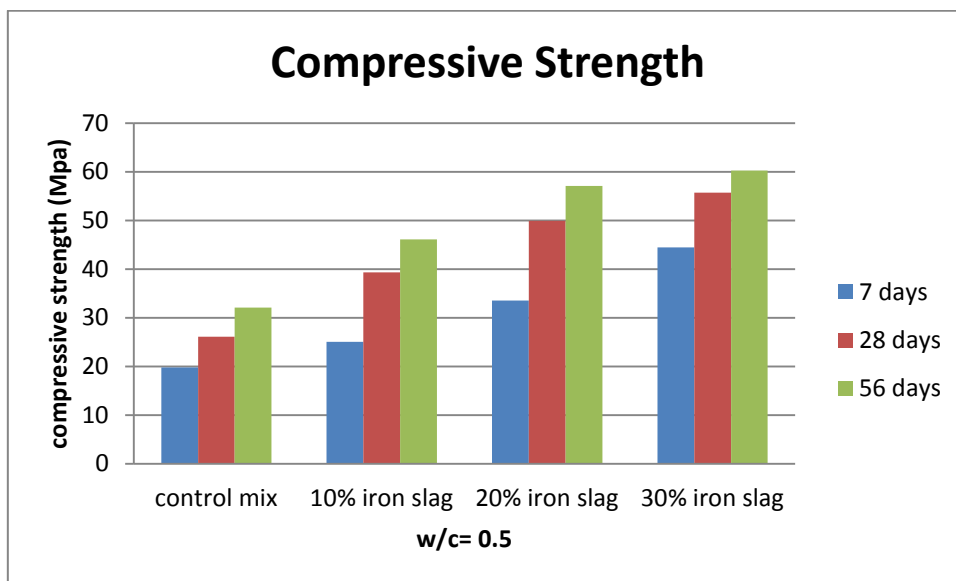


Fig. 4.1: compressive strength of iron slag concrete

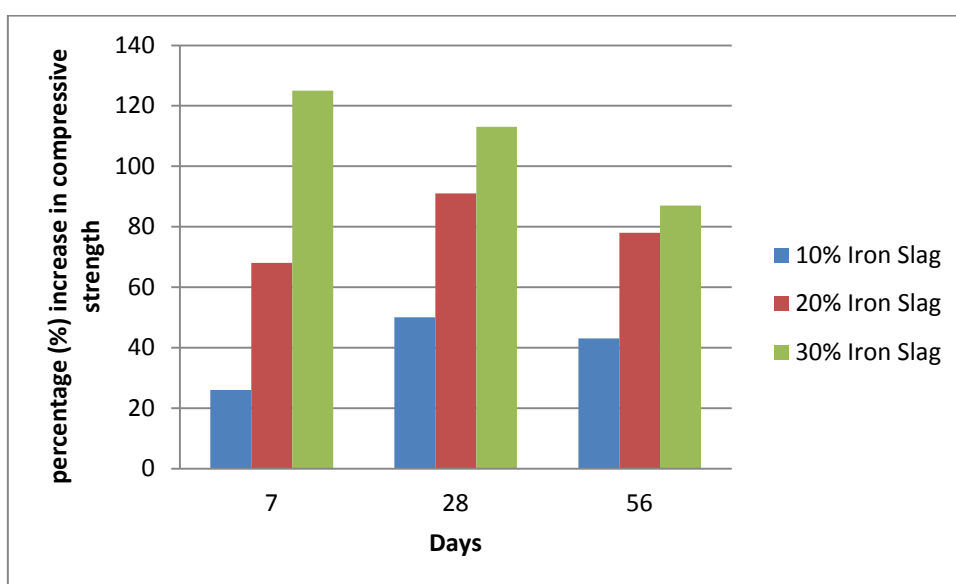


Fig. 4.2: percentage (%) increase in compressive strength of iron slag concrete

4.3 SPLIT TENSILE STRENGTH TEST

Split tensile strength studies were carried out at the age of 7, 28 and 56 days. Test results are given below in Table 4.2.

Table 4.2: Splitting tensile strength of concrete mixes with iron slag

| Mix | Splitting Tensile Strength (N/mm ²) | | | Average Splitting Tensile Strength (N/mm ²) | | |
|------------|---|---------|---------|---|---------|---------|
| | 7 days | 28 days | 56 days | 7 days | 28 days | 56 days |
| CM | 1.24 | 2.38 | 2.35 | 1.45 | 2.27 | 2.41 |
| | 1.40 | 2.17 | 2.46 | | | |
| | 1.70 | 2.28 | 2.42 | | | |
| 10% | 1.90 | 2.53 | 2.60 | 1.80 | 2.48 | 3.03 |
| | 1.80 | 2.46 | 3.45 | | | |
| | 1.99 | 2.47 | 3.04 | | | |
| 20% | 1.97 | 2.68 | 3.45 | 2.00 | 2.72 | 3.52 |
| | 2.04 | 2.77 | 3.57 | | | |
| | 2.01 | 2.72 | 3.55 | | | |
| 30% | 2.02 | 2.82 | 3.55 | 2.04 | 2.85 | 3.13 |
| | 2.06 | 2.85 | 2.64 | | | |
| | 2.04 | 2.89 | 3.20 | | | |

The split tensile strength results of concrete mix are also shown graphically in Figure 4.3. The split tensile results follow a pattern similar to compressive strength i.e. increase in the value with increase in percentage of slag replacement. However, the percentage increase in split tensile strength is smaller as compared to compressive strength. The split tensile strength increases with the percentage increase of iron slag as compared to control mix. After adding 10% iron slag in the mix, there is an increase of 24% after 7 days, 9% increase after 28 days and 25% increase after 56 days. By adding 20% and 30% iron slag, there is large amount of increase in percentage i.e. 37%, 19%, 46% and 40%, 25%, 29% after 7, 28 and 56 days, respectively.

Figure 4.4 shows the variation of percentage increase in split tensile strength with replacement percentage of iron slag. The strength gain at early age of 7 days is highest for 30% slag replacement, whereas, the strength gain at 56 days is highest if 20% of

sand in concrete is replaced by iron slag as compared to other replacement percentages (10% and 30%) taken in this work.

From the strength point of view, it can be concluded that at early age presence of more amount of iron slag as sand replacement in concrete is beneficial for improving the strength characteristics.

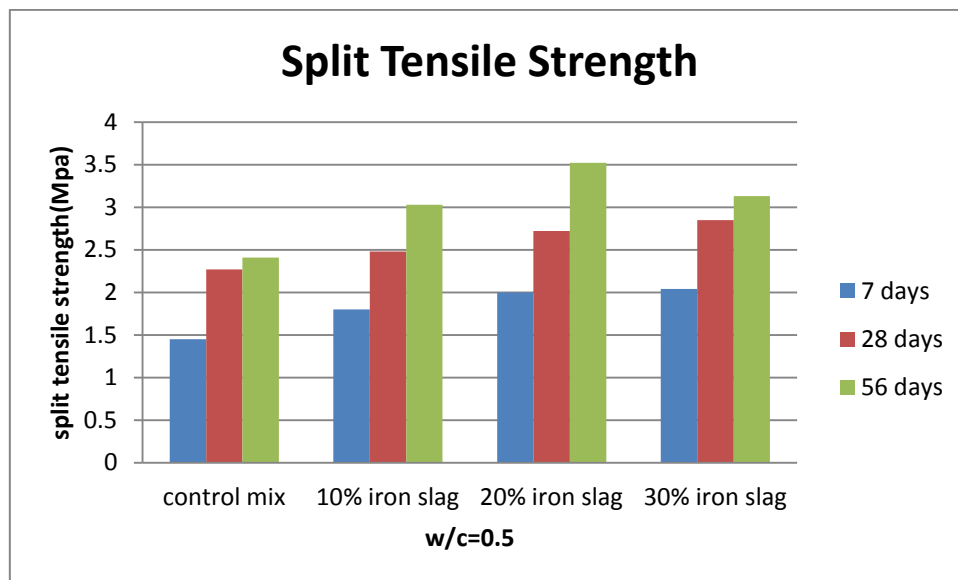


Fig. 4.3: spilt tensile strength of iron slag concrete

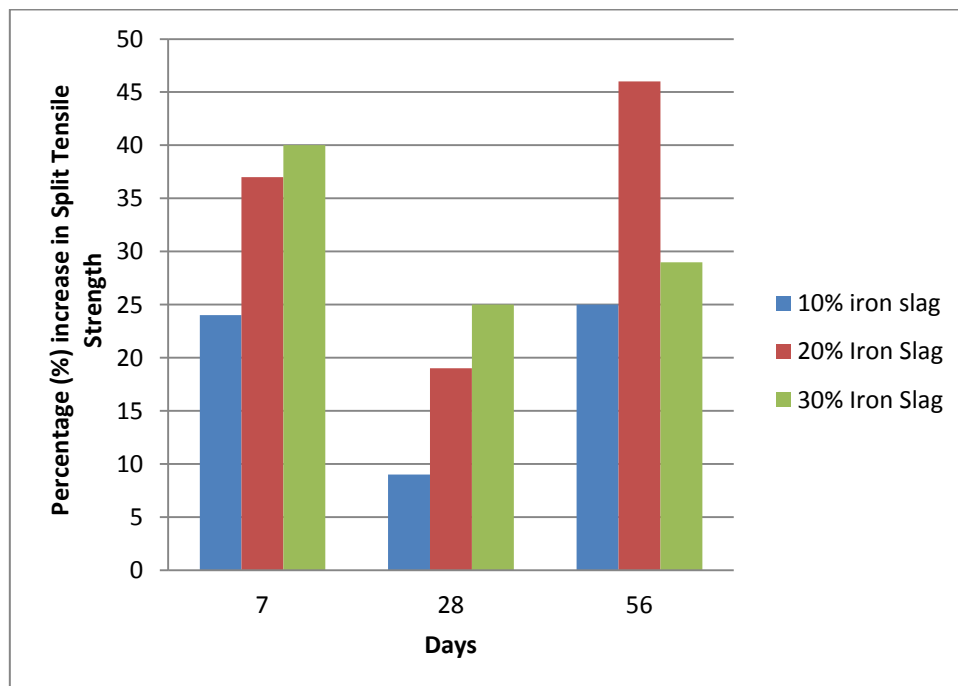


Fig. 4.4: Percentage increase in spilt tensile strength of iron slag concrete

4.4 RESISTANCE TO SULPHATE ATTACK OF CONCRETE

This test was conducted on 150 x 150 x 150mm cube specimens. The cubes were casted and cured in water for 28 days. Magnesium sulphate solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength after a further period of 7, 28 and 56 days. The cubes are tested for compressive strength and any reduction or change is noted. The compressive strength test results on immersed cube specimens are given in Table 4.3.

This compressive strength is compared with the compressive strength of specimen cured in water at same ages. The Figure 4.6 shows the increased (+) or decreased (-) in percentage of compressive strength after immersion in MgSO₄ solution and compared with the compressive strength of specimen of same size 150 × 150 × 150 mm cured in normal water at same ages.

Table 4.3: Compressive strength of concrete mixes after immersion in 50gm/liter of MgSO₄ solution

| MIX | 7 DAYS COMPRESIVE STRENGTH (MPa) | | 28 DAYS COMPRESIVE STRENGTH (MPa) | | 56 DAYS COMPRESIVE STRENGTH (MPa) | |
|-----|----------------------------------|-----------------|-----------------------------------|-----------------|-----------------------------------|-----------------|
| | <i>CONTROL (28 days)</i> | <i>IMMERSED</i> | <i>CONTROL (28 days)</i> | <i>IMMERSED</i> | <i>CONTROL (28 days)</i> | <i>IMMERSED</i> |
| 10% | 39.33 | 48.09 | 39.33 | 50.40 | 39.33 | 53.09 |
| 20% | 49.90 | 40.42 | 49.90 | 42.84 | 49.90 | 43.24 |
| 30% | 55.68 | 35.08 | 55.68 | 38.50 | 55.68 | 40.43 |

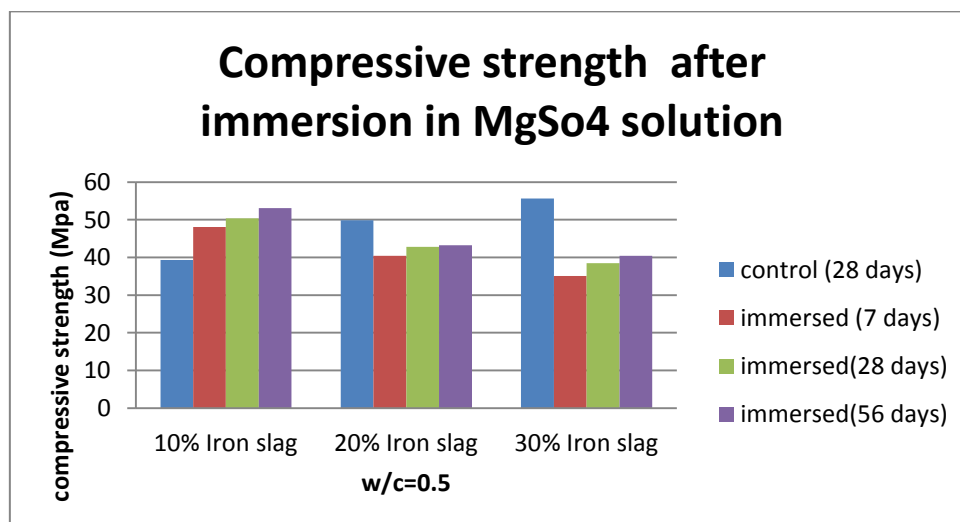


Fig4.5: Compressive strength after immersion in MgSO₄ solution (50g/l)

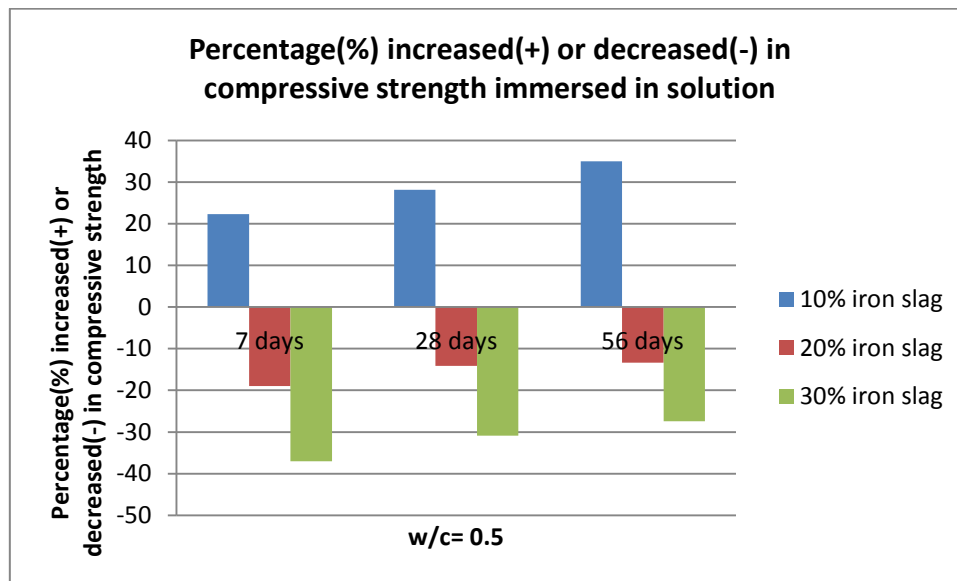


Fig4.6: Percentage(%) increased (+) or decreased (-) in compressive strength after immersion in MgSO₄ solution (50g/l) as compared with compressive strength of specimens cured in normal water at same ages.

From the table and the concerned figure, it is observed that for the mix containing 10% iron slag an increase in strength is observed at all ages as compared to the control mix even after immersing the cubes in magnesium sulphate solution. However, for both 20% and 30% replacement levels, a decrease in strength is observed when compared to the standard 28 days strength of the related concrete mix, at all ages after immersion in the sulphate solution.

This indicates that, one, the strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated and secondly, 10% slag is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

4.5 X-RAY DIFFRACTION ANALYSIS

The XRD is useful technique for the direct identification of crystalline phases present in cement concrete. However, the identification of the cement phases present in concrete is more complicated because of the poorly crystalline nature of calcium silicate hydrates which provide weak diffraction peaks and tend to be swamped by the diffraction peaks from calcium hydroxide. In addition, the peaks from minerals present in the aggregates may also interfere. The practical limits for detecting phases depend on the crystallinity and ordering of the phases.

The X-ray diffraction pattern and analysis of the concrete mixes i.e. control mix, and iron slag mixes at 28 days are shown in figure 4.7. The X-ray diffraction results show the formation of iron oxide, gedrite, sepiolite, iron manganese oxide, laihunite and Fe-ringwoodite which are responsible for increased strength characteristics. The phases identified in iron slags are shown in Table 4.4.

Table 4.4: Phases identified in iron slags

| Identified phases | Miller index of planes crystallographic (hkl) | 2 θ (Degree) | Crystallographic System |
|--|--|---|--------------------------------|
| Iron oxide (Fe ₃ O ₄) | (022);(023);(041) ;(024); (110);(124) | (26.91);(39.63);(42.67); (33.34);(54.20) | Orthorhombic |
| Gedrite (Fe,Mg,Al) ₇ Al ₂ Si ₂ O ₂₂ (OH) ₂ | (420);(062);(961); (671); (961) | (21.52);(45.89);(57.08); (49.63);(57.08) | Orthorhombic |
| Iron Manganese oxide (Fe ₃ Mn ₃ O ₈) | (111);(222);(222) ;(400) | (18.10);(36.58);(36.41); (42.34) | Orthorhombic |
| Sepiolite (Mg,Fe) ₄ Si ₆ O ₁₅ (OH) ₂ . 6H ₂ O | (133); (130);(057); | (28.10);(47.25);(50.9); | Orthorhombic |
| Laihunite FeFeO ₅ SiO ₄ | (121);(241);(141); (022) | (29.46);(54.86);(43.17); (35.72) | Monoclinic |
| Fe-Ringwoodite Fe ₂ (SiO ₄) | (220) | (30.12) | Cubic |

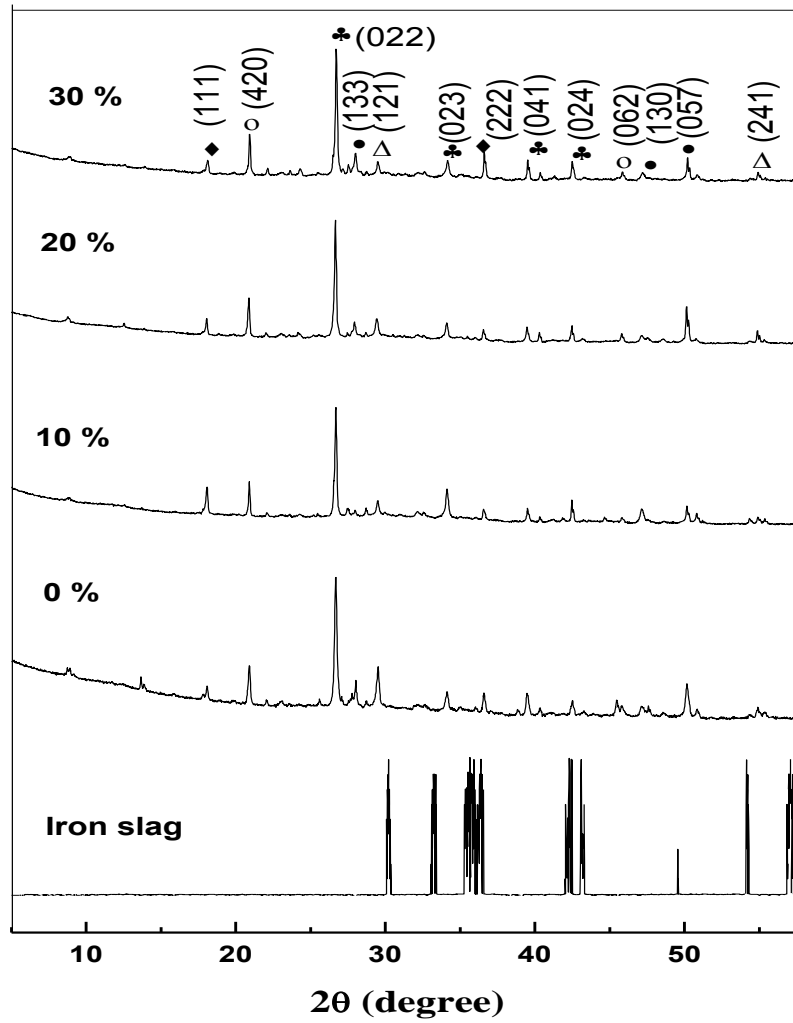


Fig 4.7: X-Ray Diffraction of iron slag and iron slag concrete mixes at 28 days

where,

- = iron manganese oxide, ° = iron manganese aluminium silicate, ♣ = iron oxide,
- ◆ = sepiolite, Δ = laihunite iron silicate



Plate 4.1 Compressive strength test in progress



Plate 4.2 Split tensile strength test in progress

5.1 GENERAL

The strength and durability characteristics of concrete mixtures have been computed in the present work by replacing 10%, 20% and 30% iron slag with the sand. On the basis of present study, following conclusions are drawn.

5.2 COMPRESSIVE STRENGTH

- After adding 10% iron slag in the mix, there is an increase of 26% after 7 days, 50% increase after 28 days and 43% increase after 56 days as compared to the control mix. By adding 20% and 30% iron slag, there is large amount of increase in percentage i.e. 68%, 91%, 78% and 125%, 113%, 87% after 7, 28 and 56 days respectively.
- The Compressive strength tends to increase with increase percentages of iron slag in the mix.
- The early age strength gain is higher as compared to later ages if 30% of fine aggregate is replaced by iron slag.

5.3 SPLIT TENSILE STRENGTH

- The Split tensile strength also tends to increase with increase percentages of iron slag in the mix.
- After adding 10% iron slag in the mix, there is increase of 24% after 7 days, 9% increase after 28 days and 25% increase after 56 days. By adding 20% and 30% iron slag, there is large amount of increase in percentage i.e. 37%, 19%, 46% and 40%, 25%, 29% after 7, 28 and 56 days respectively.
- At early age presence of more amount of iron slag as sand replacement in concrete is beneficial for improving the strength characteristics.

5.4 SULPHATE RESISTANCE

- The compressive strength of 10% iron slag specimens when immersed in 50g/l $MgSO_4$ solution gives more strength than standard mix value when immersed in water at 7, 28 and 56 days. But when the percentage of iron slag increase to 20% and 30%, the compressive strength of the mix tends to decrease when compared with the compressive strength of specimen cured in water at same ages.

- The strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated.
- 10% slag is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

5.5 X-RAY DIFFRACTION

- After 28 days, the highest peak observed as iron oxide (Fe_3O_4) due to presence of iron slag in the concrete.
- During the hydration process, the ettringite and portlandite ($\text{Ca}(\text{OH})_2$) phases are seen to diminish both after 28 days. The gedrite, sepiolite, laihunite and Fe- ringwoodite phases are seen due to the presence of high iron content in it.

5.6 SCOPE FOR FUTHER WORK

- In the present study only up to 30 per cent replacement of sand by iron slag has been considered. The other percentages i.e. 40 and 50 per cent need investigation.
- In the present study only 0.5 w/c ratio have been considered. The other ratios i.e. 0.45 and 0.55 need investigation.
- Sulphate resistance of concrete containing iron slag needs to be investigated for larger exposure time.

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