PROPERTIES OF MORTAR INCORPORATING IRON SLAG

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DECLARATION

The author hereby declares that this thesis entitled **"Properties of Mortar Incorporating Iron slag"**, 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

This is to certify that the thesis entitled **"Properties of Mortar Incorporating Iron Slag"** being submitted by **Ms. Tamara Humam Sulaiman, Roll No. 801122022** in partial fulfillment for the award of degree of **Masters of Engineering in Structural Engineering** at **Thapar University, Patiala** is a bonafide work carried out by her under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree

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Tamara

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ABSTRACT

Iron and steel slags are byproducts of the iron and steel industry. They are used not only in construction and road building, but also in other ways such as in waste stabilization. Slags are used in road bases, various types of concrete aggregates, fill, glass manufacture, mineral wool, railroad ballast, and soil conditioning. Research during the year emphasized blast furnace slags incorporated into blended cements, and used in oil well drilling, and waste stabilization, as well as various uses of steel slags. Total slag consumption increased by 6%,partly due to increased demand for slag in the construction industry and increased quantities of slags available. Domestic consumption of reported iron slag stayed the same when compared with that of 1993, while the consumption of reported steel slag increased by 17%.. In the present study effected iron slag as fine aggregate replacement on compressive strength, split tensile strength, sulphate resistance, RCPT Test of cement mortar having mix proportion 1:3 .Fine aggregate were replace with five percentage of iron slag. The percentages of replacements were 0.10, 20, 30, and 40% by weight of fine aggregate. Test were performed for compressive strength, split tensile strength, sulphate resistance, RCPT Test .Test for all replacement levels of iron slag at different curing periods (7, 28, 56 days). Test result indicates that inclusion of iron slag as partial replacement with fine aggregate enhances the properties of concrete.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The function of the mortar in the wall is to act as a bedding between stones and varies from fine joints in ashlar stonework to larger joints in rubble masonry walls. Joints are effectively reduced in size by inserting small stones and pieces of stone. Whilst acting as a bedding the mortar must also perform other functions:

1. Prevent water penetration through the joints by its physical presence almost like a masonry‘ sponge’, yet it must allow the wall to breathe and drain, porosity being a key factor in the choice of a repointing mortar.

2. Be flexible to allow movement/settlement of the structure due to thermal responses and settlement within the structure as many earlier large buildings are not designed with the modern expansion,contraction joints of today.

3. The strength of the mortar should always be less than the surrounding stones and should be considered as a sacrificial element of the wall, and viewed as a maintenance item in need of replacement possibly every century. However, the condition of stone walls cannot be viewed in isolation and repointing of any walls will not cure water ingress problems relative to other building failures such as gutters, roofs, lead work, etc, and all must be in good condition to maintain the life of the walling elements.

1.2 MORTAR TYPES

Mortars used on historic buildings fall into a number of distinct types

1.2.1 Masonry cement

These mortars are typically 1:4 or 1:5 with sand and should never be used on historic buildings. Their use in the recent past is the source of many damp problems associated with historic buildings today. Were this is encountered a decision will have to be made if it is better to remove the mortar or leave it in- situ. Any decision should be based on an inspection of the condition of the mortar (are hairline cracks allowing water to penetrate), the damage this may be causing by trapping water and the likely damaged which would be caused by trying to remove it.

1.2.2 Non Hydraulic Mortar based on lime putty

These mortars are easily worked. They provide a good bond to masonry when cured and are flexible and permeable. This type of lime mortar ('fat lime' free from impurities) does not have a chemical set and it cures slowly by reaction to air (carbonates). It must therefore be carefully supervised to avoid rapid drying out and can be vulnerable to frost and salt damage during this period. Because of this it is normally only recommended in very sheltered locations. Appropriate mixes depend on conditions and use but often fall within the proportion of 1:3. Pre mixed mortars of this type are available in Northern Ireland.

1.2.3 Artificially Hydraulic Mortars

These have similar properties to fat lime mortars but there is also a slight chemical or 'hydraulic' set introduced. This acts to strengthen a mortar while the main component carbonates and leaves it less susceptible to early damage. The chemical reaction is introduced by the addition of a reactive aggregate to the mix known as a 'pozzolan'.Brick powder and ash are two common types. Many historic mortars are of this type often because impurities in the production of the mortar introduced some pozzolanic elements. The mortars are stronger than pure lime mixes and therefore have better weathering properties though they may not be appropriate in very exposed conditions. They are often used in the proportion 1:3 to 1:4 where the pozzolan is part of the aggregate. Mortars of this type can also be bought readymade in Northern Ireland. Due to the chemical set, care needs to be taken to follow the manufacturer's instructions. A second group of these mortars is those gauged with some 'hydraulic lime' to give a chemical set rather than a pozzolan. There has been some controversy over this practice in recent years but if the hydraulic lime and the fat lime are mixed in equal proportion there will be little cause for concern. They can be used in similar exposure conditions.

1.2.4 Hydraulic Mortar based on hydraulic lime

Hydraulic lime is created from lime stones which contain impurities of silica and iron. Because of this they have a chemical reaction as well as carbonation and set in Differing degrees of hardness. There are no naturally occurring hydraulic limes produced in Ireland and the majority of this material is imported from France. Their classification is based on strength: NHL2 is also known as ‘feely hydraulic’, NHL3.5 ‘moderately hydraulic’ and NHL5 ‘eminently hydraulic’ They all have good compressive strength and are flexible and have resistance to frost within 28 days. They are often mixed with sand in the proportion 1:2-2.5. NHL2 for pointing. NHL5 for severe exposure.

1.2.5 Hydraulic Mortar based on natural cement

Mortars such as ‘Roman Cement’ were manufactured during the nineteenth century and preceded the invention of artificial or Portland cement. Ebrington Barracks in Londonderry was originally rendered with this material for example. These mortars have similar properties to artificial cement in that they tend to be very strong and prone to hairline cracks and water retention. There are some modern equivalents but they are rarely applicable in conservation work.

1.2.6 Hydraulic Mortar based upon artificial cement

For moderate exposures. The sand component can be amended to include a grit Artificial or Portland cement invented in the 1840’s has the advantage of quick curing due to its chemical set. Its strength is however much greater than that required for historic buildings and problems result from its Impermeable nature and poor flexibility. Mixes gauged with lime which maintain the proportion 1:3 have proven to be less damaging than others but with the reintroduction of a wide range of pure lime products in recent years there is no exposure situation where this should be considered the better option. Well executed lime mortars without cement are much better for long term results.

1:1:6 cement lime sand is suitable for severe exposures though it is prone to hairline cracks and needs to be very carefully monitored. The lime and sand are mixed to a ‘coarse stuff’, and this is gauged with the cement.1:2:9 cement lime sand is suitable aggregate to provide a more robust mortar. Often, this will also give a closer match to an existing mortar.1:3:12 cement lime sand is suitable for more sheltered exposures.N.B. The use of very small amounts of cement with a lime mortar can result in failures. Research carried out by English Heritage (Smeaton Report) and Historic Scotland (TAN1) has indicated this. EHS advocates that cement content should never be less than 1:3:12.

1.3 IRON SLAG

Blast-furnace slag is non-metallic product consisting essentially of silicates and alumino-silicates of calcium and other bases that is "developed in a molten condition simultaneously with iron in ablast furnace." In addition the blast furnace is the primary means for reducing iron oxides to molten, metallic iron. It is continuously charged with iron oxide sources (ores, pellets, sinter), flux stone (limestone and dolomite), and fuel (coke). Molten iron collects in the bottom of the furnace and the liquid slag floats on it, and both are periodically tapped from the furnace. The other important point slag consists primarily of the impurities from the iron ore (silica and alumina), combined with calcium and magnesium oxides from the flux stone. Sulfur and ash that may come from the coke will also be contained in the slag, which comes from the furnace as a liquid at temperatures about 1500°C. It is a man-made molten rock, similar in many respects to volcanic lavas. There are many different types of iron slag, some were produced by smelting, others by simething; some are large, some so tiny they are invisible to the naked eye when in the soil, some are magnetic, others not. Generally the blast-furnace slags in cement began to develop, fears arose that the sulfur in slag could oxidize and cause expansion of the concrete, that it could generate acid and corrode the reinforcing steel. These fears were transferred to aggregate usage with the idea that adjacent metals or concrete could be attacked, more ghosts were raised - the voids in slag could cause failures in freezing and thawing, the presence of magnesia might result in the formation of expansive periclase and disrupt structures; "falling" slags might fall or disintegrate after incorporation in structure rather than at the time of cooling, none of these horrible things have happened in a century of use of more than one and one-half billion tons of blast-furnace slag in the U.S. It is doubtful that any such disasters took place anywhere, the specifications for slag's in many countries impose unnecessary and unreasonable restrictions designed to prevent something that has never occurred in practice. Such restrictions have a habit of spreading, and finding application in one area solely because it is customary that such a limit should be imposed and it really doesn't do any harm – all of the available slags pass the test, in the case of aggregates area unnecessary requirements can, and do in some countries, prevent the use of perfectly usable materials sometimes because of efforts to make slag fit the requirements believed reasonable for natural aggregates. The Blast-furnace slag is a different material, different in particle shape, mineralogy, porosity characteristics, and density. It cannot be expected to fit precisely the mold made for another material, the national specifications for slag in the U.S. for aggregate applications utilize the same required gradings as for other aggregates. Requirements for durability, freedom from deleterious materials. are generally the same.

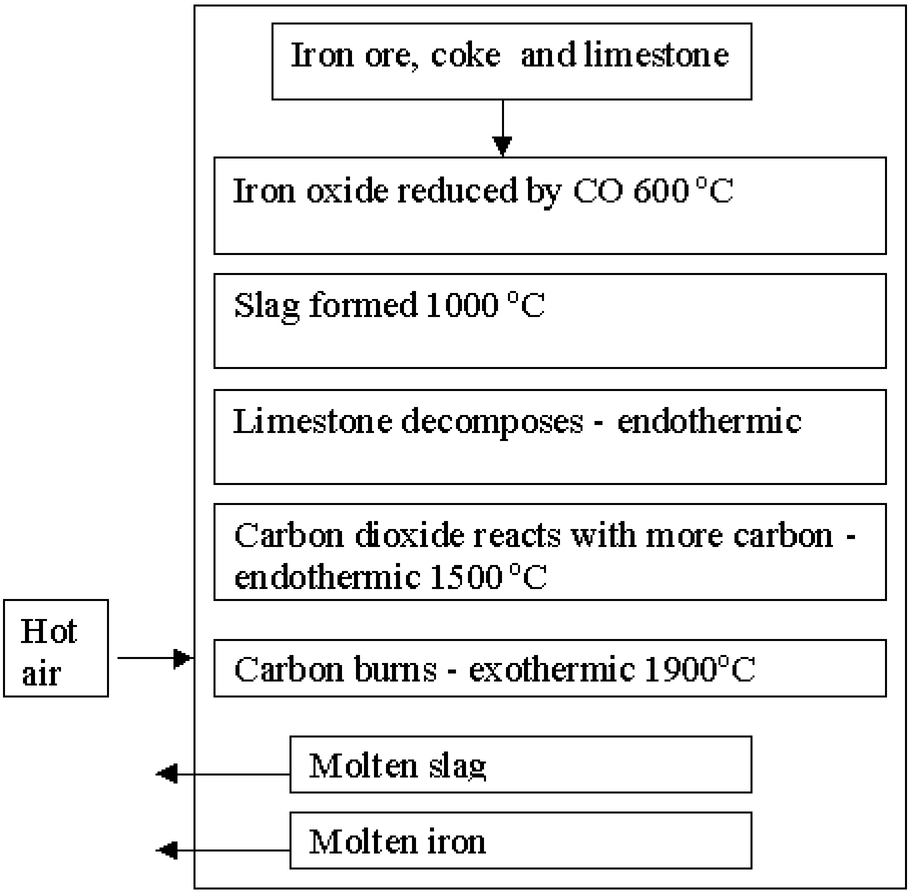

Fig. 1.1: Flow chart showing the process of iron slag (http://www.google.com/imges)

The abrasion test requirements (used as a measure of strength) are generally waived for slags because no correlation of performance with such tests has ever been established. Instead, the coarse aggregates are usually required to meet a minimum unit weight - a value that was found to correlate with strengths of concrete made with constant cement content and workability (slump), weight requirements are not equal to weights of natural aggregates, but rather are values that will produce performance at least equal to that of good quality natural aggregates. (Expanded slag for lightweight aggregate is subject to a maximum unit weight requirement, as are all lightweight aggregates.

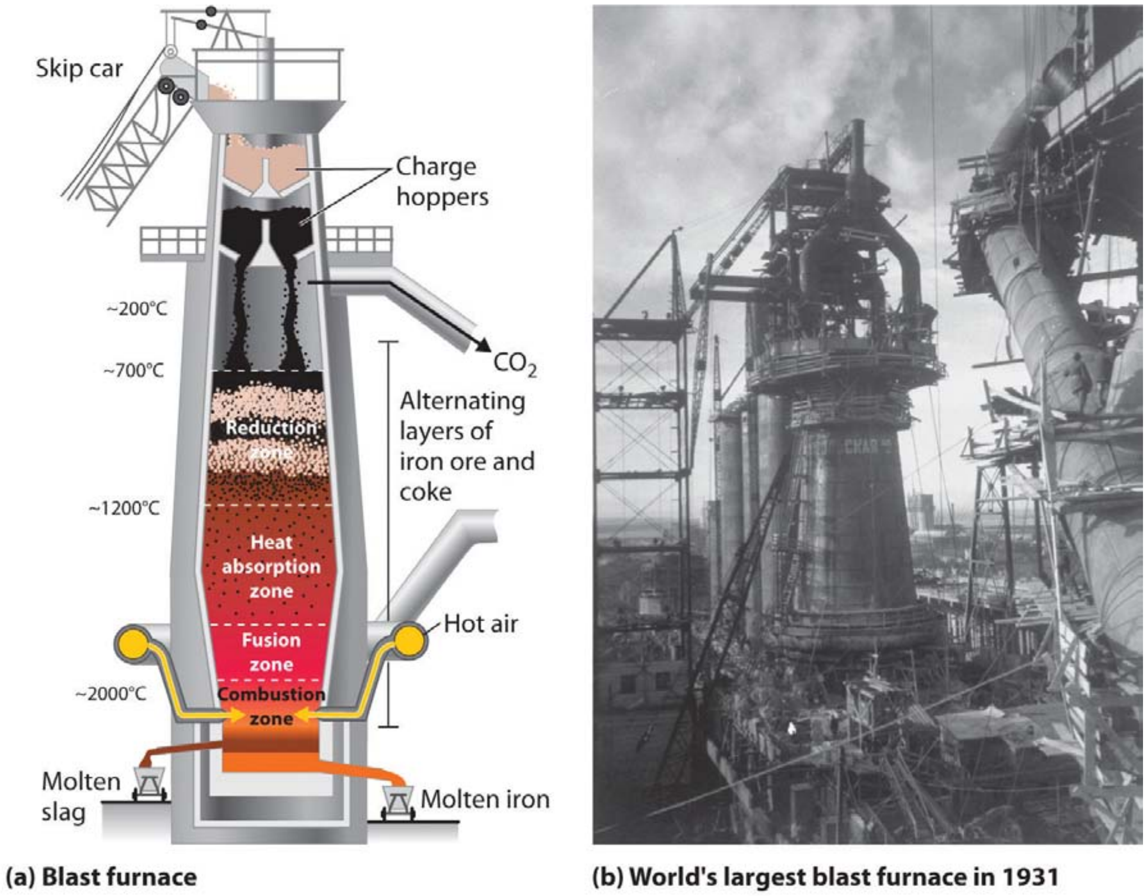

Fig. 1.2: Iron slag made in blast furnace (www.google.com)

1.4 PROCESSES OF IRON SLAG

1.4.1 Smelting

Smelting is the production of iron from ore and fuel in a smelting furnace, the products are spongy mass called an unconsolidated bloom - raw iron with a considerable amount of slag still trapped inside - and slag (waste). It can observed that slags produced vary depending on the technology used in different periods but furnace slags, including different types that are sometimes referred to as slag blocks and furnace bottoms, run slag, tap slag, dense slag or blast furnace slag.

1.4.2 Primary Smithing

It occurs in periods before the post-medieval development of casting iron, It involved the hot working (by a smith using a hammer) of the raw iron on a hearth (usually near the smelting furnace) to remove excess slag. In addition the slags from this process include smithing hearth bottoms and micro-slags, in particular tiny smithing spheres.

1.4.3 Secondary Smithing

It's involves the hot working (using a hammer) of one or more pieces of iron to create or repair an object. As well as bulk slags, the larger types such as the smithing hearth bottom – aplano-convex lump formed in the base of the hearth), smithing generates micro-slags. The two most significant are silvery-grey hammer scale flakes derived from ordinary hot working of a piece of iron (making or repairing an object) and tiny spheres from high temperature welding used to join or fuse two pieces of iron. In addition Hammer scale flakes and spheres are so small that they are difficult to see with the naked eye when in the soil — they are usually recovered by taking soil samples, the flake hammer scale is extremely magnetic (this is also the case with most, but not all smithing spheres), it can be detected with any magnet even a cheap fridge magnet and will be concentrated in the area where smithing took place i.e. around the anvil, and between it and the hearth.

Smithing hearth bottoms and furnace bottoms (the latter from Iron Age smelting) can be confused with each other, especially when the smithing hearth bottom is large, Sometimes a large proportion of the iron slag recovered may consist of small 'non-diagnostic' lumps which cannot be associated with specifically smelting or smithing. On the other hand fired and vitrified clay lumps are often the remains of a hearth or furnace, as well as consult with have the slag assessed by an iron slag specialist rather than jump to conclusions make the wrong interpretation and go on to miss other evidence that should be recorded or recovered.

1.5 TYPES OF IRON - BLAST FURNACE SLAG BY COOLING METHOD

1.5.1 AIR COOLED

The molten slag is permitted to run into a pit adjacent to the furnace or transported in large ladles and poured into a pit some distance away, solidification takes place under the prevailing atmospheric conditions, after which cooling may be accelerated by water sprays on the solidified mass, after a pit has been filled and cooled sufficiently for handling, the slag is dug, crushed, and screened to desired aggregate sizes. Graded aggregate bases for pavements, concrete - plain and reinforced, masonry units, macadam surfaces and bases, bituminous pavements, skid resistant surfaces, railroad ballast, trickling filter medium, roofing aggregate (built-up and shingle), raw material for mineral wool insulation, backfill of all types and slope protection.

1.5.2 EXPANDED

It is include treatment of the molten slag with controlled quantities of water accelerates the solidification and increases the cellular or vesicular nature of the slag, producing a light-weight product. Either machine or pit processes may be used to mix the water and molten slag. The solidified expanded slag is crushed and screened for use as a lightweight aggregate.Lightweight masonry units, lightweight concrete, fire resistant construction, floor fill, concrete masonry core fill insulation, lightweight base or fill and cement manufacture.

1.5.3 GRANULATED

The molten slag is chilled quickly to form a glassy, granular product, this different process is the most rapid of the cooling processes and little or no crystallization occurs, the granulated slag may be crushed and screened, or pulverized for various applications.Highway base and subbase, pipe backfill, agricultural liming and soil conditioning, lightweight concrete block, cement manufacture, and concrete floor fill.

1.6 CHEMICAL PROPERTIES

The chemical properties of the Blast Furnace slag is produced from the melting of iron ore and limestone or dolomite. Therefore, blast furnace slag is a lime based material and has a basic pH, the principal constituents of blast furnace slag are the oxides silica, alumina, lime and magnesia, these comprise 95 percent or more of the total, Minor elements include manganese, iron and sulfur compounds, and trace quantities of several others.

Table 1.1: Major Chemical Constituents (www.national salg.org.)

Constituent Weight Percent	**Weight Percent**
Lime (CaO)	32 to 45
Magnesia (MgO)	5 to 15
Silica (Si02)	32 to 42
Alumina(Al203)	7 to 16
Sulfur (S)	1 to 2
Iron Oxide (Fe203)	0.1 to 1.5
Manganese Oxide (MnO)	0.2 to 1.0

It should be noted, however the major oxides do not occur in free form in the slag; instead they are combined to form various silicate and aluminosilicate minerals, such as melilite (a solid solution series of akermanite and gehlenite), merwinite, wollastonite, as found in natural geological forms. The chemical composition of slag from a given source (its mineralogic composition) varies within relatively narrow limits since raw materials charged into the furnace are carefully selected and blended. The chemical properties in shown in Table 1:1 are given above.

1.7 PHYSICAL PROPERTIES

The physical properties Blast-furnace slag is tapped from the furnace as a liquid, which contains gases held in solution. The conditions of cooling control both the growth of mineral crystals and the quantity and size of gas bubbles that can escape before being trapped by solidification of the slag mass. Thus, within the limits Imposed by the particular chemical composition, the cooling conditions determine the crystalline structure and the density and porosity of the slag, dependent upon the cooling methods employed, any of three distinctly different types of product may be made from the molten blast-furnace slag.

1.8 HISTORY OF IRON SLAG

The history of the use of iron and steel slag dates back a long way and European Slag Association noted that the earliest reports (European Slag Association, 2006) on the use of slag refer to Aristotle, who used slag as a medicament as early as 350 B.C. Application of iron slag use in road building has a long history and dates back to the time of the Roman Empire, some 2000 years ago, when slag from the iron-making forging were used in base construction .Throughout history, the 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), reinforced concrete in Germany (1892), and slag bricks made from granulated slag and lime in Japan (1901). Blast furnace slag has been utilized in concrete masonry for many years. The blast furnace slag can impart many desirable properties to the masonry units such as lighter weight and increased fire resistance. Blast furnace slag products have been used successfully for agricultural applications. The physical and chemical properties of mineral wool insulation, also known as slag wool are major factors in their utility as residential and commercial insulation, pipe and process insulation, insulation for ships, mobile homes, domestic cooking appliances, and a wide variety of other applications. In the past, the application of steel slag was not attractive because vast volumes of blast furnace slag were available. Steelmaking slag has been used commercially since at least the mid-19th century. It is currently used in all industrialized countries, wherever steel is produced. Beginning in the 20th century, many new uses for steelmaking slag were developed in a variety of industries. Steel mills and slag processors work closely together to ensure that the steelmaking slag remains a high quality product for current and future applications. The application of steel slag from steel mills was not very popular until the late 1990s, for there were vast amounts of blast-furnace steel slag available, while the steel slag from steel mills was used for the manufacture of chemical fertilizers, where only the so-called Thomas steel slag, a by-product of steel production from phosphorous raw iron, was used. Now days, due to a relatively high share of electric-furnace steel in the total amount of steel produced throughout the world, thus also the growth of available amounts of this type of waste i.e. reduced production of iron in blast furnaces, steel slag is becoming increasingly important, while the application of steel slag is also rapidly growing in the developed countries. Through awareness of environmental considerations and more recently the concept of sustainable development, extensive research and development has removed slag from industrial waste into modern industrial product which is effectively and profitably used for many industrial purposes, especially as row material in cement production, landfill cover material, and the numerous construction and agricultural applications.

1.9 WORLD REVIEW OF IRON SLAG

In England and Wales iron and steel making slags are now classified as by-products Growing recognition of the finiteness of the Earth's resources and the impact of human activity on the environment has brought the focus back to slag products particularly the use of Ground Granulated Blast Furnace Slag (GGBFS) as a cement replacement. Benefits from this include potential improvements in concrete durability, conservation of mineral deposits and an overall reduction in the CO2 footprint of structures constructed using GGBFS cement. Recent release of the National Greenhouse Energy Reporting Act 2007 should also assist. Expansion of the range of slag products now available in Victoria and updates on uses in South Africa and New Zealand further demonstrate the versatility and advantage of using slag products in development of infrastructure and construction.

In New Zealand the majority of slag products are utilised in road making including asphalt and chip sealing products, however there is an increasing market for water treatment and specialised drainage products. An intensive program of monitoring of the existing applications of slag aggregates for water treatment was also undertaken, allowing SteelServ to build up a comprehensive picture of how these products performed in the field and over time. This included working with a number of leading scientific laboratories in NZ who are studying the use of a range of materials to reduce nutrients such as phosphorous and nitrates entering sensitive waterways. Melter slag filter beds were also installed at NZ Steel to reduce the levels of residual heavy metals – particularly zinc – out of the site's storm water. Partly as a result of these studies the Australasian (Iron & SteelSlag) Association commissioned an in depth examination of a number of Australasian slags and their potential to treat storm water."NZ probably leads the world in the use and study of steel industry slags to treat degraded water" says Bill Bourke. "There is considerable international interest in what we have been doing and the results we have achieved. The ASA storm water study is really a bench mark report. Which can provide consultants and their clients with a good lead and direction into the water treatment potential for these steel industry co-products .

Since around 1987, the Victorian construction industry has had available to it Ground Granulated Blast furnace Slag (GGBFS) as a cement replacement in concrete. This has become particularly important in more recent years, with the Victorian Government's push to reduce the environmental footprint of construction projects. MultiServ is making available high quality special aggregates from the One Steel (formerly Smorgon) mini mill in Victoria. MultiServ has recently won a new seven year contract with OneSteel at their Laverton Steel Mill in Victoria Australia to actively market the Electric Arc Furnace (EAF) Slag and the Caster Ladle Slag (CLS). MultiServ has been supplying mill services at the Laverton site since 1990.EAF Slag will target the Asphalt aggregates market manufacture and surface treatments where the exceptional properties of the slag can be utilized to a high potential. These materials have a high Polished Stone Value (PSV), high strength and cubical shape, form deformation resistant asphalt materials that are ideal for use in high stress areas, such as junctions, intersections and pedestrian crossings, where a high performance pavement is required. The steel slag asphalt can be used to provide a deformation resistant material with a higher skid resistance to most alternative surfaces, in one single treatment saving time and money. Traditional methods have been to repair the pavement with asphalt and then apply a specialised high grip aggregate such as calcined bauxite. Steel slag, unlike most natural aggregates maintains its skid resistance throughout its life (as measured by Scrim – on-site skid resistance test). Tests by MultiServ in Europe have found that it can actually improve as traffic increases. It is thought that due to the mineralogy and grain structure of the slag, it does not polish like a natural stone as it wears but exposes a new rough surface to maintain the skid resistance. Research undertaken by MultiServ recently has proven Caster Ladle Slag's potential in the road stabilisation market. Its pozzolanic properties make it ideal to blend with cement and lime for use in this market, reducing the cost to the end user. The slag blends pass the current VicRoads specification and due to a lower early strength (compared to cement alone) the material has a longer working time providing further operational advantages.

South Africa- Steel Slag Stabilizes Major Highway Following a series of laboratory tests by the consulting engineers, to confirm the properties of the slag, a mix design was formulated and actual laying trials were conducted on aroad in the steel mill. The success of this trial then led to the same laying contractor being awarded a contract to install a series of surface patches using steel slag asphalt on the N3 to assess the performance in the field. From this work, steel slag asphalt was then manufactured and laid on a larger scale by the on-site contractor for the N3consortium on the Van Reenan's Pass. This section of road was very steep and carried slow moving heavy lorries; the most damaging type of loading for asphalt surfaces in terms of deformation and polishing. The steel slag mixtures, which have been made with both standard grade bitumen and polymer modified binders, have out-performed the natural aggregate asphalt materials and on this basis are now specified as the preferred materials for these contracts. To date, steel slag asphalt has been used in the rehabilitation of 75km of undivided dual carriageway and in excess of 200,000 tonnes have been placed on the N3.

1.10 USES OF IRON SLAG

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, landfilling 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.

1.11 DEVELOPMENT OF IRON SLAG

Increased utilisation of granulated slag benefits the portland cement producers. 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 watercooled 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 Inc. Has developed a process called Chem Star for cement clinker production. 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 anumber 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 accidentprone 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.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

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 aluminum 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.

2.2 MECHANICAL PROPERTIES

2.2.1 Compressive Strength

Monsh and Asgarani(1999) Studied the slags from blast furnace (iron making) and converter (steel making) after magnetic separation are mixed with limestone of six different compositions. The ground materials are fired in a pilot plant scale rotary kiln to 1350 8C for 1 h. The clinker is cooled, crushed, mixed with 3% gypsum, and ground to fineness of more than 3300 cm2/g. Initial and final setting times, consistency of standard paste, soundness, free CaO, and calculate the compressive strength after 3, 7, and 28 days are measured. Samples with higher lime saturation factor developed higher C3S 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. It was concluded that, in these compositions, the LSF was higher and the alite phase, C3S, developed better. Sample M6 needs more attention because there is no converter slag, the iron content is low, and SR and AR are high; therefore, a higher firing temperature is required to decrease free CaO. 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. The 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). Successful production of Portland cement from iron slag, steel slag, and limestone is confirmed in this work, and the establishment of a cement factory near the Iron and Steel Mill in Isfahan is being studied.

Barnett et al. (2006) development the mortars containing ground granulated blast-furnace slag and portland cement was investigated. Variables were the level of GGBS in the binder, water–binder ratio and curing temperature. All mortars gain strength more rapidly at higher temperatures and have a lower calculated ultimate strength. The early age strength is much more sensitive to temperature for higher levels of ground granulated blast-furnace slag. The calculated ultimate strength is affected to a similar degree for all ggbs levels and water–binder ratios, with only the curing temperature having a significant effect. Apparent activation energies were determined according to ASTM C1074 and were found to vary approximately linearly with GGBS level from 34 kJ/mol for portland cement mortars to around 60 kJ/mol for mortars containing 70% GGBS. The water–binder ratio appears to have little or no effect on the apparent activation energy. The early age strength development of mixtures containing GGBS is highly dependent on temperature. Under standard curing conditions, GGBS mortars gain strength more slowly than Portland cement mortars. However, at higher temperatures, strength gain is much more rapid and the improvement in early age strength is more significant at higher levels of GGBS this increased temperature sensitivity of the strength gain in GGBS mortars is reflected in their higher apparent activation energies. The apparent activation energy increases approximately linearly with GGBS level. The Portland cement used in this work has apparent activation energy of 34 kJ/mol while this figure increases to 60 kJ/mol when a binder consisting of 70% GGBS and 30% Portland cement was used. These values are in broad agreement with values quoted in the literature The apparent activation energies obtained in this work are currently being used to predict concrete strength development under variable temperature conditions. Initially existing models. Which generally have been based on portland cement hydration only, are being assessed for their suitability in modeling strength development of concrete containing GGBS.

Shariq et al. (2008) In the present study the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag is studied. The compressive strength development of cement mortar incorporating 20, 40 and 60 percent replacement of GGBFS for different types of sand and strength development of concrete with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete is investigated. The compressive strength of cement mortar and concrete obtained at the ages of 3, 7, 28, 56, 90, 150 and 180 days. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days respectively. The magnitude of compressive strength of mortar for standard sand is higher than the magnitude of river sand. Incorporating 60% BFS replacement is showing lower strength at all ages and water-cement ratio for both types of sand show the mix design of concrete and mortar in Table 2.1, 2.2, 2.3. The compressive strength of OPC concrete shows higher strength as compare to the GGBFS based concrete for all percent replacement and at all ages. Incorporating 40% GGBFS is highly significant to increase the compressive strength of concrete after 56 days than the 20 and 60% replacement. Among GGBFS based concrete 40% replacement is found to be optimum. Cement mortar compressive strength. Test results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days respectively. The magnitude of compressive strength of mortar for standard sand is higher than the magnitude of river sand. In corporating 60% BFS replacement is showing lower strength at all ages and water cement ratio for both types of sand. Concrete compressive strength The compressive strength of OPC concrete shows higher strength than the GGBFS based concrete for all replacement (in percent) and at all ages. Incorporating 40% GGBFS is highly significant to increase the compressive strength of concrete after 56 days than the 20 and 60% replacement. Among GGBFS based concrete 40% replacement is found to be optimum.

Table 2.1: OPC concrete mix proportion (Shariq et al., 2008)

Mix	**Cement (kg/m3)**	**Fine aggregate (kg/m3)**	**Coarse aggregate (kg/m3)**	**Water-cement Ratio**
Mix-I	400	665	1107	0.45
Mix-II	350	680	1132	0.50

Table 2.2: GGBFS based concrete mix proportion (Shariq et al., 2008)

Mix	Direct percent replacement of GGBFS (%)	Cement (kg/m3)	GGBFS (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	w/c ratio
Mix-I	20	320	80	665	1107	0.45
	40	240	160			
	60	160	240			
Mix-II	20	280	70	680	1132	0.55
	40	210	140			
	60	140	210			

Table 2.3: Mix design for mortar 1:3(Shariq et al., 2008)

Mix	Cement (%)	GGBFS (%)	Water	Sand
1	100	0	Cement consistency (78 ml)	Standard sand
2	80	20		
3	60	40		
4	40	60		
5	80	20	cement blending consistency (81 ml) (80% Cement+20% BFS)	
6	60	40	cement blending consistency (83 ml) (60% Cement+40% BFS)	
7	40	60	cement blending consistency (86 ml) (40% Cement+60% BFS)	
8	100	0	Cement consistency (78 ml)	
9	80	20		
10	60	40		
11	40	60		
12	80	20	cement blending consistency (81 ml) (80% Cement+20% BFS)	River sand
13	60	40	cement blending consistency (83 ml) (60% Cement+40% BFS)	
14	40	60	cement blending consistency (86 ml) (40% Cement+60% BFS)	

Nadeem and Pofale (2012) the construction industry is the largest consumer of natural resources which led to depletion of good quality natural sand (Fine aggregates) This situation led us to explore alternative materials and granular slag a waste industrial byproduct is one such material identified for utilization it as replacement of natural sand. This paper highlights upon the feasibility study for the utilization of granular slag as replacement of natural fine aggregate in construction applications (Masonry &plastering) In this investigation, 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 & 0.72 respectively in Table 2.4, 2.5. The study gave comparative results for mortar compressive strength. The study comprises of the experimental results obtained show that partial substitution of ordinary sand by slag gives better results in both the applications. 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 brick crushing, pull strengths shows linear dependencies on each others. The study concluded that granular could be utilized as alternative construction material for natural sand in masonry & plastering applications either partially or fully.

Table 2.4: Proportion & Replacement Details (Nadeem and Pofale, 2012)

Mix NO	Proportions	Natural sand	Sand slag
I,II,III,IV	1:3,1:4,1:5,1;6	100	0
		75	25
		50	50
		25	75
		0	100

Table 2.5: W/C Ratio standard flow of 100±5 mm flow (Nadeem and Pofale, 2012)

Mix Proportions	W/C Ratio
1:3	0.6
1:4	0.62
1:5	0.7
1:6	0.72

Fathollah and Hashim (2010) Thirty one mix proportions of ordinary Portland cement (OPC)–slag mortars (OSM) used to study the effects of temperature on early and ultimate strengths. Three levels of slag (0%, 40%, and 50%) and different temperatures were used and mix propotion in Table 2.6. It was found that 50% is the optimum level and 60 _C with 20 h duration is also optimum. The maximum strengths obtained of optimum mortar, at 3 and 7 days, for specimens cured in the air, are 55.00 and 62.00 MPa, respectively. These strength levels are 64.50% and 66.50% greater than those without heating. The results show for 0 and 2 h heating time, the strength of specimens cured in the water are greater than those cured in the air, but for 4–26 h, this statement is reversed.

This is a novelty. Is very important in the precast industry and has many advantages for arid regions to overcome curing of concrete structures. Based on obtained experimental results in the study, for each specified material, there is an optimum temperature to obtain high early strength. It is determined that 60 _C is the optimum temperature. Duration of heating time is also very important for obtaining high early strength. For the slag used in this study.20 h heating time is optimum. Usually, as heating time increases towards the optimum, the compressive strength will be increased. Maximum strengths at 3 and 7 days, for OSM/50 cured in the air, are 55.29 MPa and 61.63 MPa, respectively. It can be seen that these strength levels are 21.78% and 20.00% more than that for OPC's specimens cured in the air, and 26.12% and 29.04% more than that for OPC's specimens cured in water, respectively. If the mortar is heated more than the optimum heating time, it is specified that this will not lead to an increase in the early strength of mortar Overcome curing of concrete structures. If the mortar is heated more than the optimum heating time, it is specified that this will not lead to an increase in the early strength of mortar. According to the results of this study and other researches. It can always be reported that thermal activation is one of the best applicable methods for the activation of OSMs.It is well known that this method is usually used in precast concrete Plants. The results obtained show the best relationship of compressive Strengths vs in Table 2.7. heating time. For the specimens cured in air and water, between OSM/40 and OSM/50, are power relations.

There is a proper relationship between the compressive strength of the specimens cured in air and water, of OSM/40 and OSM/50 at 3 days, but not for 7 days.

Table 2.6: Mix proportions for thermal activation method of OM, OSM/40, and OSM/50 (Fathollah and Hashim, 2010)

No.	**For OM, air and water cured**					
	Mix name	**OPC (g)**	**Slag (g)**	**Water (g)**	**SP (g)**	**Flow (mm)**
1	OM-air cure	1800	–	631.66	631.66	230
2	OM-water cure	1800	–	631.66	631.66	230
No	**For OSM/40, air and water cured**					
	Mix name	**OPC (g)**	**Slag (g)**	**Water (g)**	**SP (g)**	**Flow (mm)**
3	H0/0	720	480	421.11	28	225
4	H60/2	1440	960	842.22	82	230
5	H60/4,6	1440	960	842.22	90	230
6	H60/8,10	1440	960	842.22	79	230
7	H60/12,14	1440	960	842.22	79	230
8	H60/16	1440	960	842.22	82	230
9	H60/18,20	1440	960	842.22	73	230
10	H60/22,24,26	2160	1440	1263.33	70	220
No	**For OSM/50, air and water cured**					
	Mix name	**OPC (g)**	**Slag (g)**	**Water (g)**	**SP (g)**	**Flow (mm)**
11	H0/0	600	600	421.11	35	230
12	H60/2	1200	1200	842.22	76	235
13	H60/4,6	1200	1200	842.22	91	225
14	H60/8,10	1200	1200	842.22	90	235
15	H60/12,14	1200	1200	842.22	73	235
16	H60/16	1200	1200	842.22	76	235
17	H60/18,20	1200	1200	842.22	62	225
18	H60/22,24,26	1800	1800	1263.33	60	220
For optimum OSM/50 at 6 ages, only air cured						
19	H60/20	900	900	631.66	43	230

Table 2.7: Compressive strength (MPa) vs. heating time (h) for OSM/40 and OSM/50 at 60 _C. Heating (Fathollah and Hashim , 2010)

Heating time (h)	For OSM/40 3 days		For OSM/40 7days		For OSM/50 3days		For OSM/50 7days	
	Ac	Wc	Ac	Wc	Ac	Wc	Ac	Wc
0	33.21	34.48	40.29	47.43	33.61	35.59	37.03	49.61
2	36.64	38.40	44.84	49.83	36.37	37.56	42.47	50.05
4	39.71	35.39	46.17	43.22	42.60	37.71	47.49	47.31
6	45.0	41.17	47.24	43.96	45.51	40.92	51.48	49.85
8	49.61	41.61	52.33	44.85	46.36	43.37	53.13	49.04
10	47.27	40.41	55.56	50.88	50.41	43.96	55.04	48.40
12	48.97	42.49	50.93	46.41	52.63	41.84	57.65	48.27
14	52.65	47.03	56.40	48.51	48.28	41.17	57.65	52.47
16	51.73	45.92	58.99	54.83	51.23	48.36	61.25	53.44
18	55.23	46.07	59.68	50.24	53.51	48.37	59.95	52.41
20	53.08	49.01	61.11	50.24	55.29	49.95	61.63	55.31
22	50.67	43.73	58.77	51.20	50.49	48.45	60.96	56.05
24	54.64	50.12	60.37	56	51.55	48.48	2.28	55.59
26	52.48	48.97	57.12	56.76	53.04	46.63	61.25	54.77
For optimum OSM/50 at six ages-air cured F1 = 15.55 F3 = 55.09 F7 = 61.44 F28 = 71.1 6 F56 = 69.61 F90 = 73.57								

AC = air cured; WC = water cured.

Sridhar and Malathy (2011) Study on Compressive strength of cement mortar with partial replacement of fine aggregate by steel slag. There is a need for conserving resources, environment and for proper utilization of energy. Hence, there has been an emphasis on the use of waste and industrial byproducts in all areas including construction industry. Recently the growing trend towards the use of supplementary materials is emphasised, for cement mortar because of scarcity of materials. In this study the performance of cement mortar mix, applicable for casting of thin Ferro cement elements by using steel slag as sand replacement is investigated. Cement mortars of mix proportion 1:2, 1:2.5, 1:3, W/C 0.3, 0.35, 0.4 with incorporating various percentage of steel slag were designed. Performance of mortar is studied in terms of compressive strength and unit weight. Totally 99 principle mixes were prepared and test results for 28 days curing showed optimum value for mix proportion 1:2,W/C 0.4 and steel slag replacement of 30% by weight of sand can be designed in order to cast thin Ferro cement elements. Compressive strength of mortars enhances with the application of slag. The enhancement ranges between 2% to 21% for control specimen

Compressive strength value is high as 66.80N/mm2 is achieved in case of mortar 1:2; W/C 0.40, 30% steel slag replacement. While lowest value 24N/mm2 is obtained for mortar 1:3, W/C 0.35, 100% steel slag replacement. High compressive strength is obtained for mortar with steel slag of 20% in case of 1:2,W/C 0.30,1:2.5,W/C 0.3 and 1:3 W/C 0.3,while for other mixes like 1:2, W/C 0.35&0.40, 1:2.5 W/C 0.35&0.40, 1:3 W/C 0.35&0.40 the compressive strength increases up to 30% replacement and gradually decreases beyond this replacement level. The optimum mix 1:2, W/C 0.40, 30% replacement was selected only based upon the compressive strength which is used for Ferro cement laminates The partial replacement of sand by steel slag which is industrial waste not only make the product cost effective but provide apotential uilisitation of the hazardous waste which is one of the source causing environment Pollution.

Nataraja et al. (2013) performed the investigates the possibility of utilizing Granulated Blast Furnace Slag (GBFS) as and substitute in cement mortar. In order to reduce environmental problems related to aggregate mining and waste disposal. In this investigation cement mortar mix 1:3 and GBFS at 0, 25, 50, 75 and 100% replacement to natural sand for constant w/c ratio of 0.5 is considered in Table 2.8. The work is extended to 100% replacements of natural sand with GBFS for w/c ratios of 0.4 and 0.6. The flow characteristics of the various mixes and their compressive strengths at various ages are studied. From this study it is observed that GBFS could be utilized partially as alternative construction material for natural sand in mortar applications. Reduction in workability expressed as flow can be compensated by adding suitable percentage of super plasticizer. The data obtained shows that the compressive strength of cement mortar increases as the
Replacement level of GGBS increases. This increase is not substantial. The compressive strength of cement mortar for 0.4 w/c ratio is less compared with the strength of water cement ratios 0.5 and 0.6. This is because of insufficient water in the mix for compaction in Table 2.9&2.10.Too much of flaky particle in GBFS and also may be because of the improper bond between cement paste and aggregate.

Table 2.8: Proportions of Constituent Materials Used for Cement Mortar (Nataraja et al., 2013)

Combination	Cement (g)	Natural Sand (g)	GBFS Sand (g)	Water (mL)(w/c-0.5)
25% replacement of natural sand with GBFS	200	450	150	100
50% replacement of natural sand with GBFS	200	300	300	100
75% replacement of natural sand with GBFS	200	150	450	100

Table 2.9: Compressive Strength at 3, 7 and 28 Days for Natural Sand and GBFS Sand at Different w/c (Nataraja et al., 2013)

Combination	Water-Cement Ratio (w/c)	Compressive Strength (N/mm²)		
		3 days	**7 days**	28 days
Cement+100% NS	0.4	34.61	40.13	50.53
Cement+100% NS	0.5	23.94	34.91	48.02
Cement+100% NS	0.6	19.53	24.67	37.11
Cement+100% GBFS	0.4	17.41	18.11	20.62
Cement+100% GBFS	0.5	21.73	26.13	44.80
Cement+100% GBFS	0.6	16.01	22.13	36.67

However for 100% Replacement the strength decreases marginally compared to 100% natural sand. This trend is true for all ages of testing. From this it is clear that GGBS sand can be used as an alternative to natural sand from the point of view of strength. Use of GGBS up to 75% can be recommended. It is also observed that the flow of mortar.

Table 2.10: Compressive Strength at 3, 7 and 28 Days for Different Replacement of Natural Sand by GBFS Sand at w/c of 0.5 (Nataraja et al., 2013)

Combination	Compressive Strength (N/mm²)		
	3 days	7 days	28 days
25%GBFS+75%NS	27.73	35.6	49.07
50%GBFS+50%NS	27.47	33.11	48.41
75%GBFS+25%NS	26.01	31.87	48.11
100%GBFS+0%NS	21.73	25.61	44.81
0%GBFS+100%NS	23.94	34.91	48.02

2.2.2 Split Tensile Strength

Nadeem and profale (2012) The construction industry is the largest consumer of natural resources which led to depletion of good quality natural sand (Fine aggregates).This situation led us to explore alternative materials and granular slag a waste industrial byproduct is one such material identified for utilization it as replacement of natural sand. This paper highlights upon the feasibility study for the utilization of granular slag as replacement of natural fine aggregate in construction applications (Masonry &plastering). In this investigation, 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 & 0.72 respectively. The study gave comparative results for mortar flow. Mortar split tensile strength increased in 1:3 & 1:4 mix proportions at 75% granular slag replacement by 15.97 & 16.0% respectively and in 1:5 & 1: 6 mix proportions the increase was observed 11.56 & 10.29 % at 50% replacement level. The increase in strengths at 100% replacement was noted as 6.08, 7.11 & 5.39% in 1:3, 1:4 & 1:5 mix proportions respectively and in 1:6 it was below 0.59% compare to 0%. In general, the range of 25 to 75 % replacement level was found increasing the compressive strength by about 15 & 11 % respectively. Mortar split tensile strength increased by about 13 % at 50 to 75 % replacement level in all the mix proportions. It could also be generalized that mortar split tensile strength could be 10 % of mortar compressive strength in all the mixes.

2.3 DURABILITY PROPERTIES

Cerulli el at. (2003) performed the Blast furnace slag is a residue of steel production. It is a latent hydraulic binder and is normally used to improve the durability of concrete and mortars. Slag could be also used as rendering mortar for masonry and old buildings. Today, cement and hydraulic lime are the most popular hydraulic binders used to make plasters. They are characterized by a low durability when exposed to the action of chemical and physical agents. The aim of this study was to provide a comparison between the physical–mechanical properties of some renders made with ordinary Portland cement, hydraulic lime, or slag. Furthermore, an investigation was carried out to analyze mortar resistance to several aggressive conditions like acid attack, freezing and thawing cycles, abrasion, sulphate aggression, cycles in ultraviolet screening device, and salt diffusion. The specimens, after chemical attack, have been characterized from the chemical–physical [specific surface according to the BET (Brunauer–Emmet–Teller) method], crystal–chemical (X-ray diffraction, XRD), and morphological (Scanning Electron Microscopy, SEM) points of view. This study pointed out that the use of slag for rendering purposes is highly desirable, in particular under an ecological point of view. Furthermore, long plaster durability could be obtained if the product is properly optimized in order to have low water absorption, high permeability, and low content of calcium hydroxide, and absence of calcium carbonate .

Manso el at. (2011) performed Ladle furnace basic slag is a by-product of the steelmaking industry. This study examines the properties of masonry mortars made with ladle furnace basic slag and the other conventional components such as sand, cement, and admixtures. Eight different mixes were prepared and the main properties of the resulting mortars were analyzed: density, strength, porosity, microstructure and permeability. The porosity of the hardened mixes was studied by means of two complementary techniques: mercury intrusion porosimetry and computerized X-ray tomography. Test were performed to analyze the behaviour of the mixes exposed to standard detrimental agents such as frost, moisture and sulphates, as well as other special environments, such as saline water or sulphidic atmospheres. The results show that the presence of ladle furnace slag does not damage and even contributes to increasing mortar durability. Its use also decreases or eliminates volumetric contraction during mortar ageing, thereby improving certain masonry applications. The preparation of masonry mortars including ladle furnace slag (LFS) as a significant component (in this case about 22% of total mortar weight) generates savings of sand and cement and leads to a high quality product which satisfies the standard requirements for masonry mortar in relation to density, strength, porosity and permeability. The conventional mortars analyzed in this work have an adequate total porosity, higher if a plasticizer admixture is added. If LFS is suitably used in mortars, the porosity amount of mixes is similar to those of mortars made without LFS. The porosity of mortar mixtures can be analyzed in a complementary way by means of Mercury Intrusion Porosimetry and Computerised Tomography: two different techniques, the first of which reveals micro-porosity (size under about 0.17 mm),and the second macro-porosity (size up about 0.17 mm).

Sadok el at. (2012) study Mechanical characteristics and durability properties of blast furnace slag cement composites largely depend on the hydraulic activity of the slag. In this paper, a Granulated Blast Furnace Slag with a low reactivity index is used in modifying mortar composition. Microstructure and durability of mixes containing 0%, 30% and 50% of slag as substitution to OPC are respectively compared and analyzed. Water porosity, Mercury Intrusion Porosity and pore size distribution are studied after 28, 90 and 360 days of wet curing. A qualitative microstructure analysis of mortars is proposed with Scanning Electron Microscope (SEM). The durability of mortar is evaluated through capillary water absorption and chloride diffusion tests. The results indicate a finer porosity and lower water absorption for slag mortars at old ages (90 and 360 days). Moreover, lower chloride diffusion for 50% blast furnace slag substitution is Observed. Granulometry and specific surface of ground granulated blast furnace slag is similar to Ordinary Portland Cement; the total porosity of slag mortars is higher than for OPC mortar; after 90 days, the pore size distribution of slag mortars is essentially related to small pores (especially in the fraction of radius less than 50 nm) leading to a densification of the microstructure. This effect is basically induced by a good hydration of slag and is nevertheless more significant after a long period of wet curing (360 days)compressive strength is lightly influenced by 30% substitution of cement by GGBFS. However, 50% substitution led to a larger reduction in strength, even after 90 days. This variation is attributed to the moderate hydraulic activity of El Hadjar slag the sorptivity of mortar is improved by the presence of GGBFS. Especially for 50% substitution rate. However, a little evolution of capillary absorption is observed between 90 and 360 days. chloride diffusion must be analyzed in terms of effective diffusion coefficient but also of the breakthrough time. A substitution rate of 30% GGBFS induces an increase of the Breakthrough time, but with regards to OPC mortar, no major differences are observed in diffusion coefficient. However, 50% GGBFS led to better resistance of mortar to chloride penetration with a large breakthrough time and a low diffusing chloride concentration.

2.4 SULPHATE RESISTANCE

Siddique el at. (2012) study iron and steel industry by-product (GGBS) in cement paste and mortar With the increased industrialization, generation of industrial by-products has increased significantly. There are many types of industrial by-products depending upon the industry. Utilization of such types of by-products has become an enormous challenge. One such type of by-product is ground granulated blast furnace slag (GGBS) which is produced from the blast-furnaces of iron and steel industries. GGBS is very useful in the design and development of high quality cement paste/mortar and concrete. This paper presents comprehensive details of the physical and chemical properties, and hydration reaction. It also covers the workability, setting times, compressive strength, chloride and sulfate resistance of cement paste and mortar. In Portland cement mortar and concrete, sulfate attack can be minimized by reducing the presence of monosulfoaluminate and calcium aluminate hydrates. Use of GGBS to Portland cement minimizes sulfate attack in three ways: (i) GGBS does not contain any C3A, and its inclusion in concrete reduces the overall proportion of C3A in the mix; (ii) GGBS reacts with Ca (OH)2 to substantially . Three sulfate solutions were (i) 5% Na2SO4 solution having pH 12; (ii) 5% Na2SO4 and maintained at nominal PHS of 7 and 3 by automatic titration with 10% H2SO4 at regular set intervals. The results indicated that sulfate resistance of cementitious materials was dependent on its composition and on the pH of the environment. Portland cement with low C3A and low C2S performed well in all sulfate solutions. Blended cements containing slag (60% replacement) showed a much superior performance than any of the Portland cements used.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 GENERAL

The main objective of experimental program is to compare the properties of cement mortar with iron slag, used as fine aggregates .The basic tests carried out on materials used for casting mortar samples discussed in this chapter. At the end, the various tests conducted on the specimens are discussed.

3.2 Material Used

3.2.1 Portland Cement

Cement is a fine, grey powder. The basic composition of cement is given below in Table 3.1. Cement is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. IS mark 43 grade cement (Brand-J.K) was used for casting cubes and cylinders for all concrete mixes. The cement was of uniform color i.e. grey with a light greenish shade and was free from any hard lumps. 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, 3.2.

Table 3.1: Composition of ordinary Portland cement

Ingredient	**% Content**
CaO(Lime)	60-67
SiO_2 (Silica)	17-25
Al_2O_3(Alumina)	3-8
Fe_2O_3 (Iron Oxide)	0.5-6
MgO(Magnesia)	0.1- 4
Alkalies	0.4-1.3
Sulphur	1-3

Table 3.2: Physical Properties of Cement

Test Conducted	Values Obtained	Standard values
Initial Setting time	49 min	Not <30 minutes
Final Setting time	310 min	Not >600 minutes
Fineness	4.9 %	<10
Specific gravity	3.12	-
Standard Consistency, percent	29.5	-
Compressive Strength 3 days 7 days 28 days	24.8 N/mm^2 37.5 N/mm^2 47.6 N/mm^2	23 N/mm^2(minimum) 33 N/mm^2(minimum) 43 N/mm^2(minimum)

3.2.2 Fine Aggregate

The sand used for the experimental program was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and remove any dust. Properties of the fine aggregate used in the experimental work are in Table 3.3. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 3.4.

Table 3.3: Physical Properties of fine aggregates

Characteristics	Value
Specific gravity	2.59
Bulk density	1.3
Fineness modulus	2.63
water absorption	0.89

Table 3.4: Sieve analysis of fine aggregate

IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age passing	Cumulative % retained
4.75	14.5	1.45	98.55	1.45
2.36	37	3.70	94.85	5.15
1.18	246.5	24.65	70.20	29.80
600 μ	205.5	20.55	49.65	50.35
300 μ	287.5	28.75	20.90	79.10
150 μ	177	17.70	3.20	96.80
Pan	32	3.20		
Total	1000.00		SUM	262.65

Fineness Modulus of fine aggregate = ΣF/100 = 262.65 /100 = 2.63

3.2.3 Iron Slag

The slag contains metal elements (such as iron) in oxide form, however because the refining time is short and the amount of limestone contained is large, a portion of the limestone auxiliary material may remain undissolved as free CaO. These components exist in the natural world in places such as the Earth's crust, natural rock, and minerals, and the chemical composition is similar to that of ordinary Portland cement. The shape and physical characteristics of iron slag is similar to ordinary crushed stone and sand, however due to differences such as the chemical components and cooling processes, 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 3.5.

Fig. 3.1: Unprocessed of Iron slag (www.google.com)

Table 3.5: Sieve analysis of iron slag

Sieve No.	Mass Retained (gms)	%age retained	%age passing	Cumulative % retained
4.75	14	1.4	98.6	1.4
2.36	28	2.8	95.8	4.2
1.18	94.5	9.45	86.35	13.65
600 μ	189.5	18.45	67.8	32.1
300 μ	329.5	32.95	34.95	65.05
150 μ	291.5	29.15	5.8	94.2
Pan	58	5.8		
Total	1000.00		SUM	210.6
			FM =	2.10

Fineness Modulus of iron slag = ΣF/100 = 210.6 /100 = 2.10

3.2.4 Water

Generally, water that is suitable for drinking is satisfactory for use .Water from lakes and streams that contain marine life also usually is suitable .when water it obtained from sources mentioned above, no sampling is necessary .when it is suspected that water may contain sewage, mine water, or wastes industrial from plants or canneries, it should not be used in the mix, 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 discharge of harmful of wasted into the stream .In the present experimental program, potable tap water is used for casting.

3.2.5 Magnesium Sulphate

Powder form of magnesium sulphate was obtained from Swindra Instruments Corporation, Anand Pura, Patiala. It was white in color. Its solution of strength 5% by adding it to water was made and used for sulphate resistance test.

3.3 MIX DESIGN

Mix has been designed based on Indian Standard Recommended Guideline BIS:10262-1982 .The proportion for the mortar, as determined is 1:3 with percentage of water 747 (Lit) . The mix designation and quantities of various materials for each designed mortar mix have been in Table 3.6.

Table 3.6: Mix Design

Mix	Ratio% Iron slag	Cement (gm)	Sand (gm)	Iron Slag (gm)	Water (lit.)
M1	0	200	600	0	747
M2	10	200	540	60	747
M3	20	200	480	120	747
M4	30	200	420	180	747
M5	40	200	360	240	747

3.4 BATCHING, MIXING AND CASTING OF SPECIMENS

A careful procedure was adopted in this batching; mixing and casting operations. The fine aggregates were weighed first with an accuracy of 0.5 grams. The mixture was prepared by handing mixing on a watertight platform .OPC having 43 grades was used in casting .Three proportions of fine aggregates are replaced with iron slag and thoroughly mixed. Then water added carefully so that no water was lost during mixing. Nine clean and oiled modules for each category were then placed on the vibrating table respectively for the cubical samples for compression strength testing. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould.

Cubical mould of size 70.5 mm x 70.5 mm and Cylinder mould of size 100 mm x 200 m were used to prepare the specimens .Care was taken during casting and vibrator was used for proper compaction. All the specimens were prepared in accordance with Indian standard specifications IS: 516-1959. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry.

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition .After that these were demoulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing .The ambient temperature for curing was 27 ± 20 C.

3.5 TESTING OF SPECIMENS

For each mix 45 Cubes mould of size 70.5×70.5 mm were used to prepare the mortar specimens for the determinations the compressive strength, sulfate resistance and 45 cylinder mould of size 100 mm×200 mm were used to determinations the split tensile strength , And RCPT test . All specimens were prepared in accordance with Indian Standard Specifications BIS: 516-1959. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry. Mortar cubes 70.5x70.5 mm were tested for the determinations the compressive strength; sulfate resistance and cylinder 100 mm ×200 mm for determination of split tensile strength, RCPT per Indian Standard Specifications BIS: 516-1959.

3.6 TESTS CONDUCTED

3.6.1 Compressive Strength Test

Cubical specimen of size 70.5mm were cast for conducting the compressive strength test for each mix. In this test 9 cubes from each mix were tested .The test was carried at the end of 7, 28, 56 days of curing .The compressive strength of any mix was taken as the average of three cubes the cured specimens are removed from the curing tubes and the area of loading face of cubes determined, and then placed at the center between plates of Universal Testing Machine, and two level surfaces of the cube should meet the plates (the face of casting can’t be in touch of the direct loading). The load is applied till failure occurred and the load where that happened is recorded. In this test nine cubes from each mix were tested. The test was carried at the end of 7, 28 &56 days.

3.6.2 Splitting Tensile Strength Test

Only cylinders specimens of size 100 mm x 200 mm were used to determine split tensile strength of the mixes. In this test 9 cylinders from each mix were tested .The test was carried at the end of 7, 28, 56 days of curing. The cylindrical specimens were placed horizontally between loading surface of the compression testing machine and load was applied along the vertical diameter until failure of the cylinders. In order to reduce the magnitude of high compressive stress near the point of application of the load, narrow packing strips of plywood of 30 mm wide, 3 mm thick and 150 mm long were placed between the specimen and loading platens of the testing machine .

3.6.3 Sulphate Resistance Test (C1012/C1012M)

In this test 9 specimens are immersed in the water containing MgSO4 solution for7, 28, 56 days and checked for if there is any change in its weight, colour, appearance and compressive strength. The sulphate solution is add at the rate of 5mg/ 1000ml (as per per ASTM C1012).Magnesium sulphate leads to a complete reaction until all the magnesium is used up.

3.6.4 Rapid Chloride Permeability Test (C1012/C1012M – 10)

This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test method is applicable to types of concrete. This test method consists of monitoring the amount of electrical current passed through 2-in. (51-mm) thick slices of 4-in. (102-mm) nominal diameter cores or cylinders during a6-h period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration. In the AASHTO T277 (ASTM C1202) test, a water-saturated, 50-mm thick, 100-mm diameter concrete specimen is subjected to a 60 V applied DC voltage for 6 hours using the apparatus shown in Figure 3.2 In one reservoir is a 3.0 % NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria included as Table 3.7. This test, originally developed by Whiting [1981], is commonly (though inaccurately) referred to as the “Rapid Chloride Permeability Test” (RCPT). This name is inaccurate as it is not the permeability that is being measured but ionic movement. In addition, the movement of all ions, not just chloride ions, affects the test result (the total charge passed).There have been a number of criticisms of this technique, although this test has been adopted as a standard test, is widely used in the literature [Saito and Ishimoiri, 1995; Good speed at al., 1995; Thomas and Jones, 1996; Samaha and Hover, 1996] and has been used to limit permeability in at least one standard [CSA/S413-94]. The main criticisms are: (i) the current passed is related to all ions in the pore solution not just chloride ions, (ii) the measurements are made before steady-state migration is achieved, and (iii) the high voltage applied leads to an increase in temperature, Concrete Sample » 60 mm 2.8 M NaCl Solution Sealed on All Faces Except One especially for low quality concretes, which further increases the charge passed Lower quality concretes heat more as the temperature rise is related to the product of the current and the voltage. The lower the quality of concrete, the greater the current at a given voltage and thus the greater heat energy produced. This heating leads to a further increase in the charge passed, over what would be experienced if the temperature remained constant. Thus, poor quality concrete looks even worse than it would otherwise. These objections all lead to a loss of confidence in this technique for measuring chloride ion penetrability. In addition, they also lead to a loss of precision. The ASTM C1202 statement on precision, based upon work by Mobasher and Mitchell [1988], states that the single operator coefficient of variation of a single test has been found to 12.3 %, and thus two properly conducted tests should vary by no more than 35 % if done by one person. The between-laboratory measurement is naturally less precise and a single test result will have a coefficient of variation of 18.0 %. To minimize the variation, three samples are generally tested and the average value reported. However, a precision statement is also given for this type of test and it is stated that the average of three samples should not differ by more than 29 % between two separate laboratories [ASTM C1202].Another difficulty with the RCPT test is that it depends upon the conductivity of the concrete being in some way related to the chloride ion penetrability. Thus, any conducting material present in the concrete sample will bias the results, causing them to be too high. This would be the case if any reinforcing steel is present, if conductive fibers are used (e.g. carbon or steel), or if a highly ionic conductive pore solution is present [ASTM C1202]. This pore solution effect may be noticed if calcium nitrite is included as a corrosion inhibiting admixture, and other admixtures may also have this effect [ASTM C1202]. Because these conductors all influence the results so that a higher coulomb value than would otherwise be recorded is determined, the method still could serve as a quality control test. It can qualify a mix, but not necessarily disqualify it [Ozyildirim, 1994]. If an acceptably low rating is achieved, it is known that the concrete is not worse than that, at least within the precision of the test method. Nord test setup.

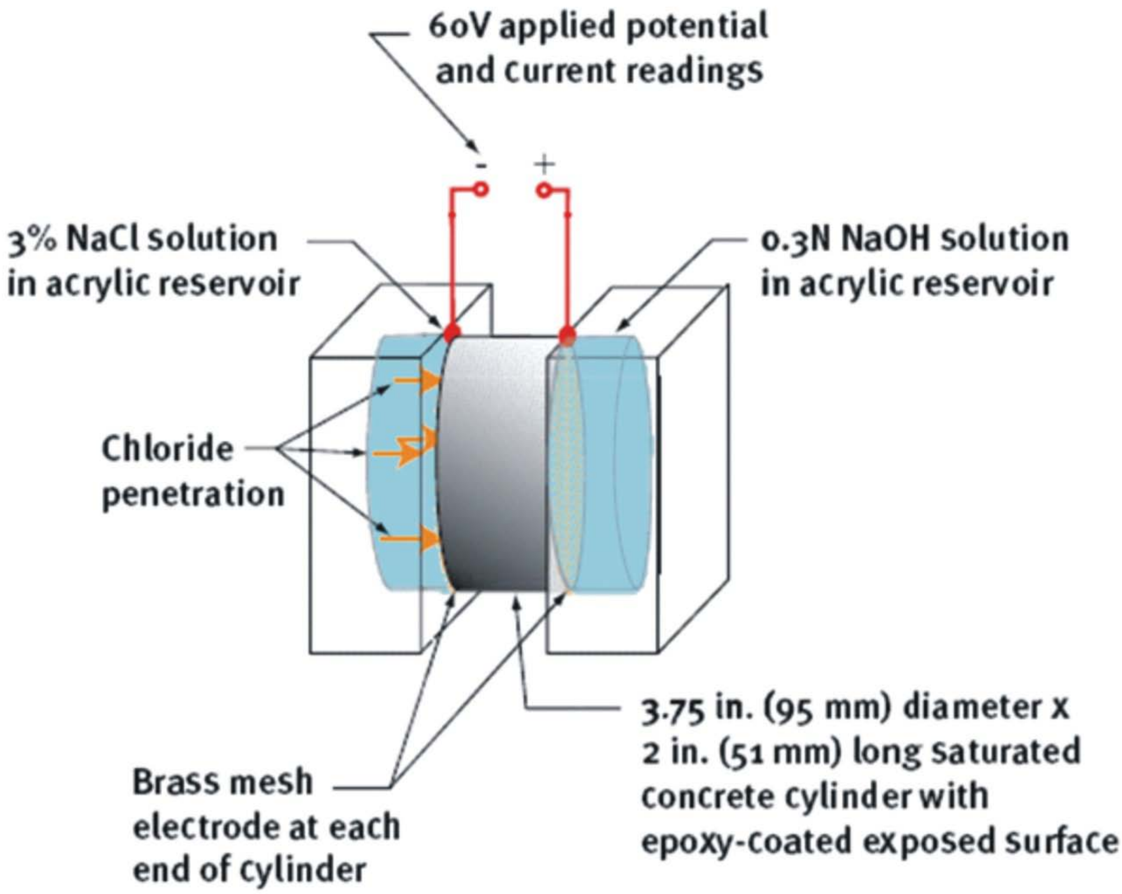

Fig. 3.2: Schematic of rapid chloride permeability test setup (www.google.com)

Table 3.7: Chloride Ion Penetrability Based on Charge Passed (ASTM C1202)

Charge Passed (coulombs)	**Chloride Ion Penetrability**
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100 Negligible	Negligible

Chapter 4

Results and Discussion

4.1 GENERAL

Various properties of cement mortar incorporating iron slag at various replacement levels with fine aggregate. Tests were conducted for Compressive strength, Splitting Tensile Strength, Sulphate resistance, RCPT Test are discussed and comparisons between the various mixes are represented.

4.2 COMPRESSIVE STRENGTH TEST

In this test, the values of compressive strength for different replacement levels of sand with iron slag contents (0%, 10%, 20%, 30%, 40%) at the end of different curing periods (7 days, 28 days, 56 days) are given in Table 4.1 .These values are plotted in figure 4.1 which show the variation of compressive strength with fine aggregate replacement at different curing ages respectively.

Table 4.1: Compressive strength of mortar mixes with iron slag

Mix	**Compressive strength (Mpa)**		
	7 days	28 days	56 days
0%	24.51	31.39	32.31
10%	28.93	34.57	35.71
20%	30.02	35.24	38.45
30%	35.79	36.00	49.70
40%	36.20	38.37	51.03

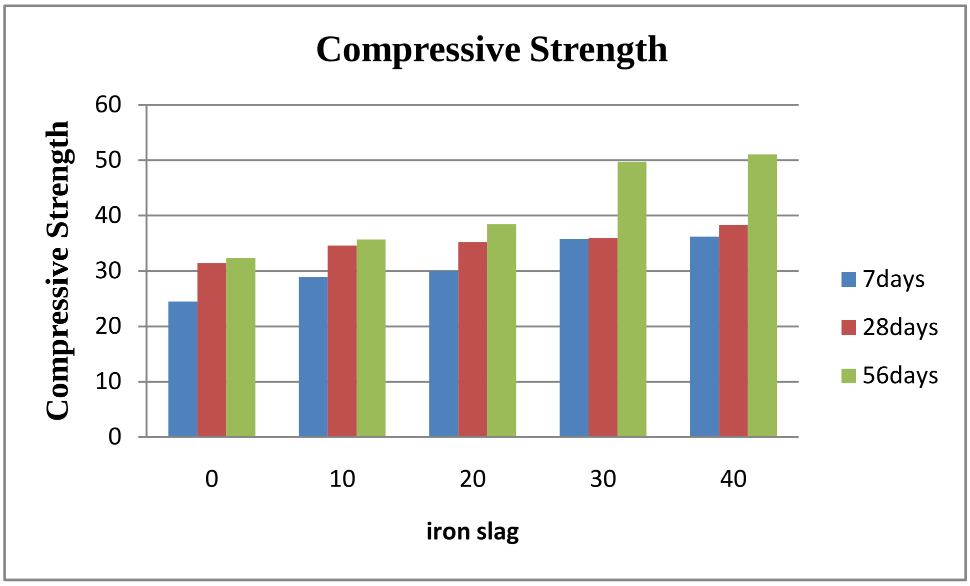

Fig. 4.1: Compressive strength of mortar with iron slag

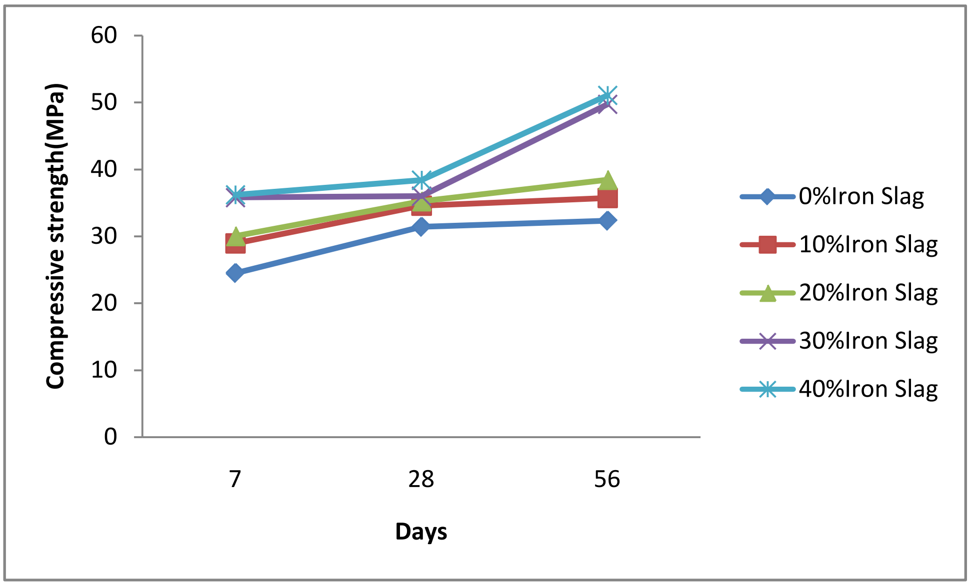

Fig. 4.2:Compressive Strength of mortar with age

Figure 4.1 shows the variation of compressive strength with replacement with iron slag. The compressive strength increase with the increase the percentage of iron slag as compared to control mix. After adding 10% iron slag in the mix, there is increase of 18% after 7 days , 12% increase after 28 days and 15% increase after 56 days. By adding 30% and 40% iron slag , there is large amount of increase in percentage ie 59%, 20%, 60% after 7, 28 and 56 days respectively. In figure 4.2 shows the variation of compressive strength of mortar with age at different percentage of iron slag, (0, 10, 20, 30, and 40%).

4.3 SPLITTING 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. As seen in table, test results indicated that 5 to 10 percent by weight replacement of sand by iron slag enhances strength for short and long terms. After adding 10% iron slag in the mix, there is an increase of 3% after 7 days, 9% increase after 28 days and 5% increase after 56 days. By adding 30% and 40% iron slag , there is large amount of increase in percentage i.e. 4%, 34%, 20% and 38%, 56%, 22% after 7, 28 and 56 days, respectively., when compared to control mix at age of 28 days. These results are represented graphically below in Fig. 4.3, 4.4.

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

Mix	**Split Tensile Strength**		
	7days	28days	56days
0%	2.03	2.11	2.57
10%	2.08	2.30	2.71
20%	2.09	2.25	3.04
30%	2.11	3.01	3.09
40%	2.79	3.29	3.13

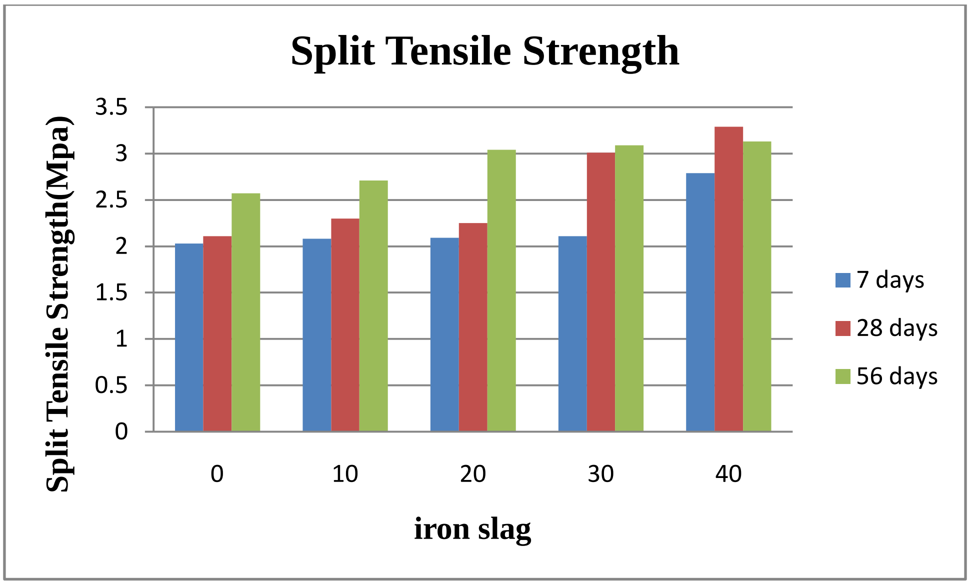

Fig. 4.3: Spilt tensile strength of mortar with iron slag

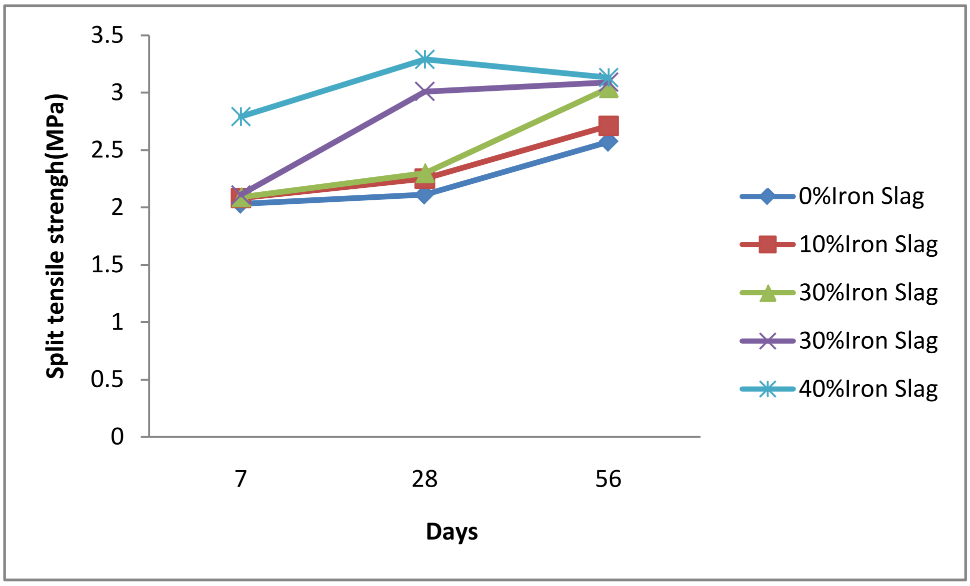

Fig.4.4: Split tensile strength of mortar with age

Figure 4.3 shows the variation of split tensile strength with replacement with iron slag. The split tensile strength increase with the percentage increase of iron slag as compared to control mix. After adding 10% iron slag in the mix, there is increase of 3% after 7 days, 9% increase after 28 days and 5% increase after 56 days. By adding 20% and 30% iron slag , there is large amount of increase in percentage 3%, 6% ,38 %, 46% and 40%, 25% , 29% after 7, 28 and 56 days respectively.

In figure 4.4 shows the variation of split tensile strength of mortar with age at different percentage of iron slag, (0, 10, 20, 30 and 40%).

4.4 RESISTANCE TO SULPHATE ATTACK OF MORTAR

It was found that due to sulphate attack the compressive strength of mortar. (Using 0%, 10%, 20%, 30%, 40% replacement levels with iron slag) depend on the percentage of iron slag used. The variation of compressive strength due to sulphate attack was shown in Table 4.3.

Table 4.3: Compressive Strength after Sulfate Resistance

MIX	**7 DAYS COMPRESIVE STRENGTH (MPa)**		**28 DAYS COMPRESIVE STRENGTH (MPa)**		**56 DAYS COMPRESIVE STRENGTH (MPa)**	
	CONTROL (28 days)	IMMERSED	CONTROL (28 days)	IMMERSED	CONTROL (28 days)	IMMERSED
10%	34.57	36.19	34.57	37.89	34.57	38.21
20%	35.24	37.32	35.24	40.57	35.24	42.44
30%	55.6836	31.84	36	32.68	36.00	35.37
40%	38.37	30.05	38.37	33.71	38.37	35.91

increase in 10% iron slag specimen after immersed in solution after 7, 28 and 56 days respectively. When the replacement of iron slag increase in the mix, the strength of specimen tends to decrease as compare to the compressive strength cured in water at same ages. Figure 4.5 shows the 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 $MgSo_4$ solution and compared with the compressive.

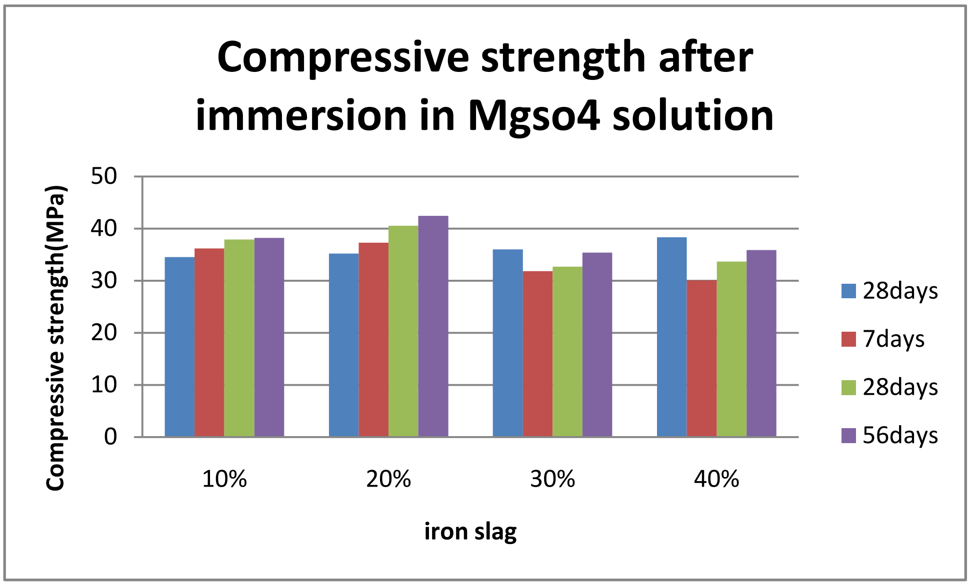

Fig.4.5: Compressive strength after immersion in $MgSo_4$ solution (50g/l)

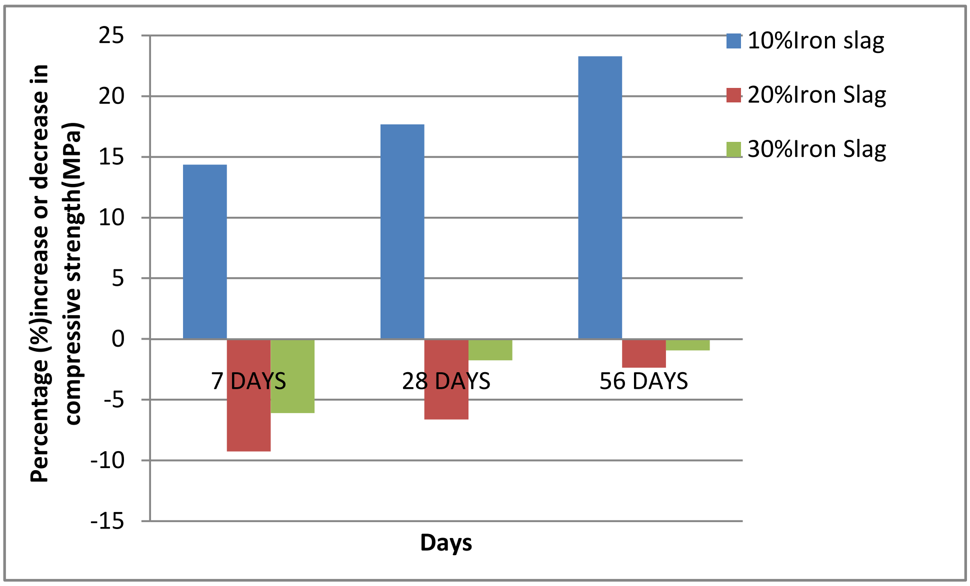

Fig4.6: Percentage(%) increased (+) or decreased (-) in compressive strength after immersion in $MgSo_4$ solution (50g/l) as compared with compressive strength of specimens cured in normal water at same ages.

Fig.4.7: Compressive strength in progress

Fig. 4.8: Split tensile strength in progress

4.5 RAPID CHLORIDE PERMEABILITY TEST

In this test, the values of Rapid Chloride Permeability Test for different replacement levels of sand with iron slag contents (0%, 10%, 20%, 30%, 40%) at the end of curing period (28 days) are given in Table 4.4 .These values are plotted in fig 4.9, which show the variation of compressive strength with fine aggregate replacement at different curing ages respectively. At 0% the chloride permeability its moderate and at (10, 20, 30, 40%) the chloride permeability its low.

Table 4.4: RCPT Test

% (Iron slag)	RCPT value	Chloride Ion Penetrability
0%	2230	Moderate
10%	1920	Low
20%	1750	Low
30%	1500	Low
40%	1280	Low

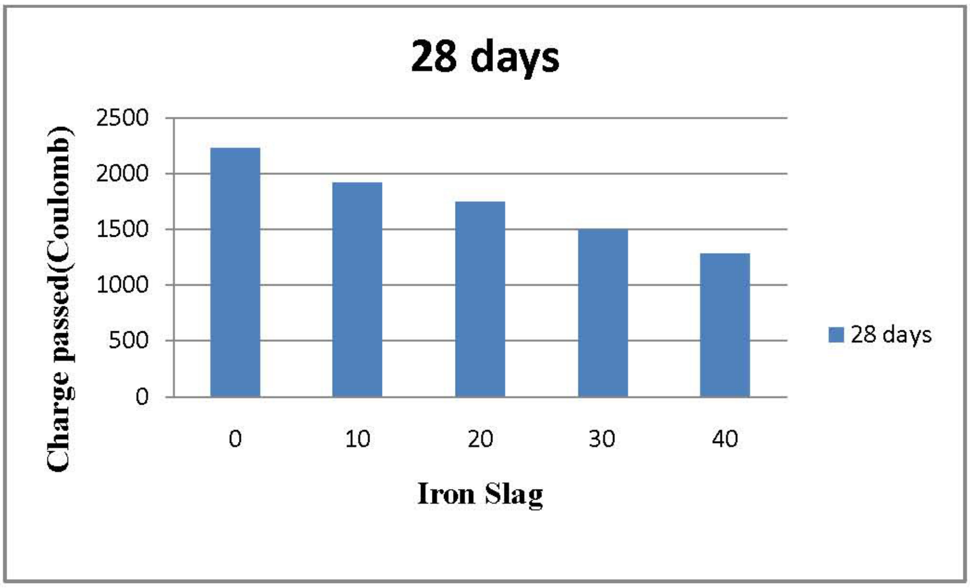

Fig 4.9: Rapid Chloride Permeability Test

CHAPTER 5

CONCLUSIONS

The following Conclusions are drawn from this study:

1. Compressive strength of mortar increase with increase in sand replacement with different replacement levels of iron slag .At each replacement level, increase in strength was observed with the increase in age. It increases up to 40% replacement.
2. The split tensile strength also increases with increase in sand replacement with different replacement levels of iron slag. At 40% it gives max split tensile strength.
3. In the Sulphate resistance test. The Compressive strength increase with increase percentages of iron slag in the mix.
4. 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.

   20% slag is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

   .
5. The value of RCPT test at 0% Chloride Ion Penetrability its moderate and at (10, 20, 30 &40% its low).

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