CHAPTER I
INTRODUCTION

1.1 GENERAL

Cement is one of the main ingredients used for the production of mortar and concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon dioxide gas into the atmosphere, a major contributor of green house effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact.

The total amount of the by-products generated by the industry worldwide every year exceeds 900 million tonnes. Many of the by-products contain toxic elements which are harmful if not disposed in safe manner. The cement and concrete industry provides a safe place for these by-products because most of the toxic metals can be permanently bound into the portland slag cement hydration products. Substantial energy and cost savings can result when the industrial by-products are used as a partial replacement of cement.

1.2 CONCRETE AND ENVIRONMENT

Concrete is an extraordinary and key structural material in the human history. According to Brunauer and Copeland (1964), “Man consumes no material except water in such tremendous quantities”. There is no doubt that with the development of human civilization, concrete will continue to be a dominant construction material in the future. However, the development of modern concrete industry also introduces many environmental problems such as pollution, waste dumping, emission of dangerous gases and depletion of the natural resources.

Presently portland cement and supplementary cementitious materials are the cheapest binders which maintain or enhance the performance of concrete. However, out of these binders, production of Portland cement is very energy exhaustive along with CO₂ production. About 1 tonne of CO₂ is produced in manufacturing of each tonne of
Portland cement. Thus, cement production accounts for about 5% of total global CO₂ emissions (Nixon, 2002). On the other side of the spectrum, in order to reduce the rate of climate changes, a global resolution to an 8% reduction in greenhouse gas emissions by 2010 was set in the Kyoto Protocol in 1997. Developed countries are much aware for its need and a climate change tax was introduced by them. In this connection UK Government also introduced same kind of tax on 1st April 2001, in order to achieve its target of a 12.5% reduction in greenhouse gas emissions which is the government's domestic goal of a 20% reduction in CO₂ emissions by 2010. Therefore, it is evident that, in order to keep its position as a dominant material in the future, the model of concrete industry needs to be shifted towards “Sustainability”.

1.3 SUSTAINABILITY AND CONCRETE INDUSTRY

The worldwide damage to concrete and concrete structures has impaired the record of concrete as a material of everlasting durability (Mehta et al., 1994). In the present living conditions on globe, the use of resources, energy and the degree of atmospheric pollution are most important. Portland cement is both resource and energy intensive. One of the major reasons for much lower resistance of modern portland cement concrete to penetration by aggressive ions is the significant changes that have occurred in chemical composition of portland cement during last four decades (Al-Amoudi et al., 1994). The construction industry has a direct influence on world resources, energy consumption and carbon dioxide emission. The rapid growth of population, the depletion of world’s resources, the environmental impacts on concrete leading to deterioration of concrete and the distraction of infrastructure due to natural disasters demand for sustainable concrete.

Sustainability is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). Therefore, sustainable development is disturbed with protecting the world’s resources and sharing its benefits for the betterment of generations to come. In order to fulfill its commitment to the sustainable development of the whole society, the concrete of tomorrow will not only be more durable, but also should be developed to satisfy socioeconomic needs at the lowest environmental impact (Aitcin, 2000). In his prediction for the 21st century concrete construction, Swamy (2001) stated “bearing in mind the technical advantages of incorporating Pulverized
Fuel Ash, slag, Silica Fume and other industrial pozzolanic by-products in concrete, and the fact that concrete with these materials provides the best economic and technological solution to waste handling and disposal in a way to cause the least harm to the environment. PFA, slag, SF and similar materials thus need to be recognized not merely as partial replacements for portland cement, but as vital and essential constituent of concrete. Thus, using various wastes or by-products in concrete is a major contribution of the 21st century concrete industry to the sustainable development of human society.

By-products from various industries cause a major environmental problem around the world. In order to encourage waste recycling and prevent waste dumping, a landfill tax has also been imposed in the developed countries. However, the waste dumping is still a serious environmental issue throughout the world. Among various by-products generated by the industries, Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) have attracted much attention by concrete researchers. As stated by Mehta (1998), “the goal of sustainable development of the cement and concrete industries is, therefore, very important, and it can be reached if we make a serious effort for complete utilization of cementitious and pozzolanic by-products produced by thermal power plants and metallurgical industries.”

1.4 USAGE OF POZZOLANIC MATERIALS IN CEMENT AND MORTAR

Romans were first to use volcanic ash, from the village Puzzoli near Naples, as building material. Hence the name puzzolana is derived (Lea, 1956). Pozzolanic definition by ASTM C618 (1978) is a siliceous or siliceous and aluminous material which, in itself, possess little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

The addition of the pozzolanic materials with ordinary portland cement, a century old practice, is an alternative practice in the construction industry. The longevity of old monuments proves the efficiency of the lime blended material.

Fly ash, Ground Granulated Blast furnace Slag, Rice Husk ash, High Reactive Metakaolin, Silica fume are some of the pozzolanic materials which can be used in concrete as partial replacement of cement (Venkatesh Babu and Nateshan, 2004). When pozzolanic materials are incorporated to concrete, the silica present in these materials
are act with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C-S-H), which improve durability and the mechanical properties of concrete (Faseyemi Victor Ajileye, 2012).

Investigations were undertaken by Singh and Garg, (2007) to establish the possibilities of using a much higher amount of flyash content in combination with fluorogypsum, lime sludge and portland cement to enhance the physico-chemical properties of cementitious binder.

The development of ternary blends made by a superfine mineral admixture like silica fume (SF) is an alternative possible way to overcome the drawback of binary blends. The SF in the ternary blend improves the early age performance of concrete and the flyash is continuously improving the properties of hardened concrete (Nabil Bouzoubaa et al. 2004)

According to several researchers, ternary blends are vastly superior to portland cement concrete in terms of durability of structures (Mullick, 2007). The development of ternary blended cement has been the subject of investigation for the past three decades (Berry, 1980). Some of the developed countries are currently producing the ternary blended cement including a combination of flyash, slag and silica fume (Nehdi, 2004).

Rice Husk Ash utilization by the construction industry is not new. The process was investigated by Mehta (1977), who observed that it was possible to obtain ashes rich in silica (in crystalline or glassy state) depending on the combustion conditions. In the glassy case, highly pozzolanic ashes would be obtained, which would be adequate for partial substitution of portland cement.

Superplasticizers, also known as high range water reducers, are chemicals used as admixtures where well-dispersed particle suspensions are required. These polymers are used as dispersants to avoid particle aggregation, and to improve the flow characteristics (rheology) of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete (HPC). This effect drastically improves the performance of the hardening fresh paste. Indeed the strength of concrete increase whenever the amount of water used for the mix decreases.
Superplasticizer is based on a blend of specially selected organic polymers. It is instantly dispersed in water. Superplasticizers are used to enhance the fluidity of the concrete without adding water. These molecules physically separate the grains of cement by neutralizing their force of attraction.

1.5 NECESSITY OF THE PRESENT INVESTIGATION

Cement is a widely used construction material for various types of structures for its structural stability and strength. The usage, behavior as well as the durability of concrete structures, built during the last first half of the century with Ordinary Portland Cement (OPC) and plain round bars of mild steel, the ease of procuring the constituent materials (whatever may be their qualities) of concrete and the knowledge that almost any combination of the constituents leads to a mass of concrete have bred contempt. Strength was stressed without a thought on the durability of structures. As a consequence of the liberties taken, the durability of concrete and concrete structures is on a southward journey; a journey that seems to have gained momentum on its path to self-destruction (Ramaswamy and Biswas, 2008). It is known that permeability controls deterioration of concrete in aggressive environments, because the processes of such deterioration as carbonation, chloride attack and sulfates attack are governed by the fluid transportation in concrete. Fillers and pozzolanic materials are introduced to improve the strength and other properties of concrete for necessary conditions (Alexander and Magee, 1999).

In the present investigation an attempt is made to find various mechanical properties based on the experimental results, mathematical models were elaborated to predict the strength of mortar cubes with partial replacement of cement by different admixtures with 5%, 10% and 15% of total powder content by weight. Strength of cubes with Portland Slag Cement (PSC) and Ordinary Portland Cement (OPC) after 3, 7, 28, 90 and 365 days of curing and also durability properties after 60 days, were analysed to evaluate the effect of addition content, the time of curing and the compressive strength changes. The micro level structure configuration was studied by generating high resolution images of the various mortar cubes prepared by the replacement of different cement samples with different types of admixtures by using Scanning Electron Microscopy (SEM). The chemical compounds formed in different combinations of cement mortar were identified by assessing the spatial variations in the
chemical compositions which was done by using X-Ray Diffractive studies (XRD) by correlating the results obtained for finding the predominant elements found by using standard Joint Committee on Powder Diffraction Standards (JCPDS) data in Energy Dispersive X-Ray Spectroscopy (EDS). The test results of selected properties of binders and hardened mortar cube with admixtures were also included. It was analysed from the test results that the mortar cubes with admixtures were characterized by advantageous applicable qualities.

1.6 THESIS ORGANIZATION

The thesis consists of six chapters and the chapter-wise content is summarized below.

The first chapter deals with the importance and necessity of utilizing the unwanted materials from the various industries as mineral admixtures in various quantities as ingredients for cement.

A critical review of literature relevant to the present study is reported in the second chapter. It describes the importance of various mechanical and durability aspects of cement mortar cubes with and without superplasticizer with the replacement of cement by different percentages of mineral admixtures. It also presents briefly the past study related to the scope of the present investigation.

The third chapter presents the scope and objectives of the present study. A detailed description of the various materials used and the various experiments that are conducted are presented in the fourth chapter.

Fifth chapter focuses on the various mechanical properties such as normal consistency, initial setting time, final setting time, soundness test and compressive strength with 5%, 10% and 15% partial replacement of two types of cements i.e., portland slag cement and ordinary portland cement with different mineral and chemical admixtures. Durability related properties were investigated using Acid attack test, Alkaline attack test, Sulphate attack test and Rapid chloride permeability test and results are presented and discussed in the fifth chapter. Scanning Electron Microscopy (SEM) is used to generate high resolution images of the various mortar cubes prepared by the replacement of different cement samples with different types of admixtures, are also presented in same fifth chapter which was done by finding the various predominant
elements present and compounds formed by using XRD analysis and matching with the standard data present in Joint Committee on Powder Diffraction Standards (JCPDS) which is an organization that maintains the data base of inorganic and organic spectras. The concluding remarks of the present study along with the scope for further work are presented in the sixth chapter.
CHAPTER II
REVIEW OF LITERATURE

2.1 GENERAL

Concrete is the most widely used construction material because of its versatility, economy, availability of raw materials, strength and durability. Concrete can be designed to withstand the harshest environmental conditions while taking on the most inspirational and imaginable shapes and forms. The material has been well accepted by the society in this age and present era can be termed as “Concrete Age” in the history of mankind (Biswal et al., 2011). Scientists, Engineers and academicians are continuously working for better concrete from strength and durability standpoint with the help of innovative chemical admixtures and supplementary cementing materials (SCMs). In addition, the use of SCMs conserves energy and has environmental benefits because of reduction in carbon dioxide emission as a result of reduction in manufacture of portland cement. Strict air pollution controls and regulations have produced an abundance of industrial byproducts that can be used as supplementary cementing materials. Typical examples are flyash, ground granulated blast furnace slag, microsilica, rice husk ash, metakaolin and natural pozzolans which can be used incorporated in concrete addition or as partial cement replacement.

2.2 SUPPLEMENTARY CEMENTING MATERIALS

Supplementary cementing materials are often used in concrete or mortar mixes to reduce cement contents, improve workability, increase strength and enhance durability through hydraulic or pozzolanic activity. Utilization of these byproducts in cement/concrete not only prevents them from being land-filled but also enhances the properties of concrete in fresh and hardened states.

2.2.1 FLY ASH

The Fly Ash (FA), also known as pulverized fuel ash, is produced from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz and shale) fuse in suspension and float out of the combustion chamber along with exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called flyash.
In cement industry, fly ash is often used to improve the fresh and hardened properties of concrete and mortar. The desirable properties obtained by using fly ash include improving the workability of fresh concrete, reducing the initial hydration temperature in mass concrete applications, increasing the sulphate and chloride resistance of the resulting reinforced concrete and improving the ultimate strength.

2.2.1.1 Environmental Benefits of Using Fly Ash

Utilization of fly ash in cement and concrete has significant environmental benefits such as

(a) Increasing the life span of concrete roads and structures by improving concrete durability.

(b) Reduction in energy use and green house gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement.

(c) Reduction in amount of coal combustion products that must be disposed in landfills.

(d) Conservation of other natural resources and materials.

2.2.1.2 Benefits of Using Fly Ash in Cement or Concrete

Inclusion of fly ash in cement or concrete has several benefits. Benefits to concrete vary depending on the type of fly ash, proportion used, other mix ingredients, mixing procedure, field conditions and placement. Some of the benefits of fly ash in concrete are

(a) Reduced Bleeding and Segregation: Bleeding and segregation are considerably reduced with the use of fly ash as a mineral admixture in concrete and thus improving the pumpability of concrete. This is due to the lubricating effect of glassy spherical fly ash particles and increased ratio of solids to liquid.

(b) Improved Workability: The spherical shape and glassy surface of fly ash particles permit greater workability for equal water to cement (w/c) ratio. In other words, w/c ratio may be reduced for equal workability.
(c) **Reduced Heat of Hydration:** Hydration of cement paste is accompanied by liberation of heat that raises the temperature of concrete. Because of the slower pozzolanic reactions, partial replacement of cement by fly ash results in release of heat over a longer period of time, and the concrete temperature remains lower slowly. This is of immense importance in mass concrete where cooling, following a large temperature rise, can lead to cracking.

(d) **Higher Ultimate Strength:** The addition of fly ash with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages (less than 90 days) will ultimately exceed the strength of straight cement concrete mixes.

(e) **Reduced Permeability:** The decrease in water content combined with the production of additional cementitious compounds reduces the pore interconnectivity due to reinforcement of pore structure of concrete resulting in reduced permeability which results in the long term durability and resistance to various forms of deterioration.

(f) **Increased Resistance to Sulphate Attack:** Fly ash in concrete increases the resistance and potentially corrosive salts that penetrate into concrete and cause steel corrosion with accompanying cracking and spalling of concrete. Fly ash induces three phenomena that improves the sulphate resistance (i) consumes the free lime making it unavailable to react with sulphate. (ii) reduced permeability prevents sulphate penetration into the concrete and (iii) replacement of cement reduces the amount of reactive aluminates available.

(g) **Improved Resistance to Corrosion:** Fly ash addition to concrete improves the long term corrosion resistance of concrete. The reaction of fly ash with Ca(OH)$_2$ produces a denser concrete and thus inhibits the ingress of chloride ions takes place at a slower rate.

(h) **Increased Resistance to Alkali-Silica Reactivity (ASR):** Fly ash reacts with available alkali in the concrete, which makes them less available to react with certain silica minerals contained in the aggregates.
2.2.1.3 Case Studies

Ramakrishnan et al. (1981) reported an increase in setting time with the use of high-calcium fly ash in concrete. Lane and Best (1982) concluded that use of fly ash as partial replacement of cement usually reduces the water content for a given consistency. With proper proportioning of the concrete, cohesion and plasticity are adequate and bleeding is reduced and workability is increased. Lane and Best concluded that the influence of fly ash on setting time is less than the influence due to cement fineness, water content and ambient temperature. Roadway and Ikdirko (1989) studied the setting times of concrete with varying percentages (0, 56, 68 and 76%) of fly ash of the total cementitious material. High fly ash concrete mixes exhibited increasingly greater setting times of 22-42.5 h with increasing fly ash content from 56 to 76% compared to 7.6 h for the control mix without fly ash. They observed that delays appeared to be related to the problem of compatibility between cementitious materials and superplasticizer to maintain workability. Sivasundaram et al. (1990) investigated the setting time of high-volume fly ash (HVFA) concrete mixes, and concluded that the initial setting time of 7.50 h was comparable to that of control concrete, whereas the final setting time was extended by about 3 h as compared to that of the control concrete. Verma et al. (1998) studied the feasibility of setting up of sintered fly ash aggregate production plant in India. From the studies, it was found that based on the factors like transportation etc., 20% profit can be earned from the fly ash aggregate plants. Papadakis (2000) explains, in the case where portland cement is replaced by fly ash, the final setting will exceed that of the control only if the content of active silica in the fly ash is higher than that in the cement.

Carette and Malhotra (1987) studied the effect of Canadian fly ashes on the compressive strength of concrete mixes in which cement was replaced with 20% fly ash in all the mixes up to an age of 365 days and concluded that the compressive strength continued to increase with age, indicating pozzolanic action of fly ashes. Swamy and Mahmud (1986) reported that concrete containing 50% low-calcium bituminous fly ash as partial replacement of cement developed 20-30 MPa compressive strength at 3 days, 60 MPa at the age of 28 days. Md. Moinul Islam and Md. Saiful Islam (2010) studied the effects of fly ash on strength development of mortar by partial replacement of ordinary portland cement with six percentages (10%, 20%, 30%, 40%, 50% and 60%) of class F fly ash by weight. Compressive as well as tensile strengths of the mortar...
specimens were determined at 3, 7, 14, 28, 60 and 90 days. Test results showed that strength increases with the increase of fly ash up to an optimum value, beyond which strength values start decreasing with the further addition of fly ash and concluded that the optimum amount of cement replacement in mortar is about 40% which provided 14% higher compressive strength and 8% higher tensile strength as compared to OPC mortar. Karim et al. (2011) studied the strength development of mortar and concrete containing fly ash and concluded that the strength development of concrete containing a particular level of FA replacement is the same or higher as compared to OPC concrete at later age. For about 20 to 40% replacement of FA, no remarkable reduction in strength of concrete is observed at 7 days, and eventually, greater strength gaining characteristic also appeared. Amarnath et al. (2012) studied the influence of fly ash replacement on strength properties of cement mortar and found that 10% fly ash is the optimum dosage for maximum strength.

Beth Brueggen et al. (2010) demonstrated that grinding fly ash increases reactivity. Scanning Electron Microscopy was then done to investigate the physical effects of the grinding process on the fly ash particles in order to identify the mechanism by which grinding leads to improve concrete properties. Vidivelli and Mageswari (2010) conducted a study on the performance of partially replaced cement by fly ash at dosages of 10% and 20% and also the concrete specimens were examined by scanning electron microscopy represented a dense microstructure which increases the strength in concrete. Shafiq et al. (2012) have investigated the durability and long term performance of mortar cubes made of fly ash blended cement with ordinary portland cement and concluded that fly ash blended cement mortar specimens exhibited 10% to 15% lower porosity when measured at equilibrium conditions, which resulted in 6% to 8% higher compressive strength of FA blended cement mortar specimens. A valid statistical correlation between values of compressive strength, porosity and the degree of saturation was obtained. Measured values of chloride permeability index of fly ash blended cement mortar were obtained as one fourth to one sixth of those measured for OPC mortar specimens, which indicates high resistance against chloride ion penetration in FA blended cement specimens, hence resulting in a highly durable mortar.
2.2.2 GROUND GRANULATED BLAST FURNACE SLAG

Ground granulated blast furnace slag (GGBS) is a byproduct from the blast furnaces used to make iron. Blast furnaces are fed with a controlled mixture of iron ore, coke, and limestone and operated at a temperature of about 1500°C. When iron ore, coke, and limestone melt in the blast furnace, two products are produced, molten iron and molten slag. The molten slag is light and floats on the top of molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone. The process of granulating the slag involves cooling of molten slag through high pressure water jets. This rapidly quenches the slag and forms granular particles generally not bigger than 5 mm. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises around 95% non-crystalline calcium-aluminosilicates. The granulated slag is further processed by drying and then grinding in a rotating ball mill to a very fine powder, which is GGBS.

2.2.2.1 Environmental Benefits of Using GGBS

The use of GGBS as partial cement replacements with lower environmental burdens offers opportunities for significant reductions in energy use and carbon dioxide emissions. Proportions of up to 70 or even 80% can be used with advantage in suitable situations. The use of GGBS in concrete results in following environmental benefits:

(a) Saves energy
(b) Reduces emission of carbon dioxide.
(c) Conserves natural resources.

2.2.2.2 Benefits of Using GGBS in Cement or Concrete

Use of GGBS in cement and concrete results in the following advantages

(a) Improved Workability and Compaction Characteristics
(b) Increased Pumpability
(c) Enhanced Strength and Durability
(d) Reduced Permeability
(e) High resistance to chloride penetration
(f) High resistance to Sulphate Attack
(g) High Resistance to ASR
(h) Low Heat of Hydration
(i) Suppresses Efflorescence
(j) Production of GGBS involves virtually zero CO\textsubscript{2} emissions and no emissions of SO\textsubscript{2} and NO\textsubscript{x}

2.2.2.3 Case Studies

Stutterheim (1968) from their investigations concluded that slag concretes have appreciably better workability than portland cement concretes, allowing for reduction in water quantity. Meusel and Rose (1983) experimented with highly active slag at contents of 30-50\% in concrete. They observed that the inclusion of slag improved the workability of concrete mixes, but greater improvement was achieved with high slag content, and higher fineness of slag did not have significant effect on the workability. As per ACI Committee 226 (1987), the greater solid volume and higher fineness of slag allow more coarse aggregate to be used without the loss of workability. This often reduces the stickiness of the mix. Wainwright and Ait-Aider (1995) investigated the effect of GGBS on the setting times of cement and concluded that the setting times of cement were increased with the increase in the GGBS content.

According to Neville (1981), slag cements tend to be finer than Portland cement, but the strength gain in first 28 days is somewhat slower. At later ages, the strength is similar. Hogan and Meusel (1981) reported strength of slag-blended cements made with using a slag with a target fineness of 55cm\textsuperscript{2}/g. They found that mortar strengths of cements developed more slowly than the controls for the first 3 days, after which the rate of strength development increased sharply and are greater than the controls and the optimum dosage of slag for the strength development was 40\%. Wan et al. (2004) reported the effect of GGBS on the compressive strength and activity index of mortars up to the age of 28 days. They concluded that the mortars containing 3-20 \mu m particles of GGBS, the higher was its long term strength and the compressive strengths increased with the increase of the surface area of GGBS. Barnett et al. (2006) investigated the strength development of mortar cubes containing GGBS and Portland cement. Variables were the level of GGBS in the binder, water- binder (w/b) ratio and curing temperature. All mortars gain strength more rapidly at high temperatures and
have a lower calculated ultimate strength. The water-binder ratio appears to have little or no effect on the apparent activation energy. Shariq et al. (2008) studied the effect of strength development on cement mortar and concrete incorporating GGBS and concluded that 40% replacement is found to be optimum than 20% and 60%. Compressive strength of blast furnace slag concrete with different dosages of slag was studied as partial replacement of cement by Atul Dubey et al. (2012) and concluded that the optimum replacement of GGBS powder to cement without change in the compressive strength is 15%.

Hogan and Meusel (1981) reported that partial replacement of high-alkali cement with slag dramatically reduces the likelihood of alkali aggregate reaction in concrete. Fearson (1986) observed that increasing the slag contents in portland cement slag mortars increased the sulphate resistance substantially. The sulphate resistance of blended cements made with slag was less influenced by the water to cement ratio than by the amount of cement replaced by slag. Cheng et al. (2005) studied the influence of GGBS on the rapid chloride permeability (RCPT) of concrete. ASTM C 1202 (1997) procedure was adopted for carrying out RCPT. RCPT results indicated that the charge passed through GGBS blended cement specimen was very less which represented highest chloride ion penetration resistance.

SEM micrographs given by Daube and Bakker (1986) indicated that the addition of GGBS modifies the products and the pore structure in a hardened cementitious material. It was found that a great number of calcium hydroxide (CH) and large capillary pores (0.05-60μm) were found in OPC specimens. But few needle shape ettringite existed in GGBS concrete specimens and the capillary pores were less than (10-50μm) which could be filled up with pozzolanic reaction product such as low density C-S-H gel. Gao et al. (2005) studied the morphology of the hydration products in concrete made with (GGBS) using SEM. Cement was replaced with 40% GGBS. The self-hydration cement and GGBS produces Ca(OH)$_2$. In a saturated solution of Ca(OH)$_2$, the pozzolanic reaction of GGBS consumes Ca(OH)$_2$. Therefore, the quantity of Ca(OH)$_2$ crystals depends on its formation and reaction rates in a Ca(OH)$_2$ saturated solution. When the formation rate is faster than reaction rate, then, amount of Ca(OH)$_2$ crystal and height of the XRD peak increases.
Radwan et al. (2012) studied the influence of substitution of OPC by GGBS up to 70% on the properties of cement composite pastes up to 12 months. After one year the composite cement pastes containing 50-70% slag exhibit suitable strength values compared to without slag sample. Also XRD results show that C-S-H intensified with available increase indicating more dense structures and large amount of additional C-S-H in the presence of slag content.

2.2.3 MICROSILICA

Silica fume or micro silica is a byproduct of the smelting process in the silicon and ferrosilicon industry. Microsilica has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. By using silica fume along with superplasticizers, it is relatively easier to obtain compressive strengths of order of 100-150MPa in laboratory.

Addition of Micro silica to concrete improves the durability of concrete through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to sulfate attack. Improvement in durability will also improve the ability of silica fume concrete in protecting the embedded steel from corrosion.

2.2.3.1 Environmental Benefits of Using Microsilica

The following environmental benefits can be achieved by using microsilica as a partial replacement material in place of cement:

(a) Very low permeability to chloride and water intrusion
(b) Enhanced durability
(c) Increased toughness
(d) Increased abrasion resistance on decks, floors, overlays and marine structures
(e) Superior resistance to chemical attack from chlorides, acids, nitrates, sulfates and sea water and life-cycle cost efficiencies.
(f) Improved alkali-silica reaction resistance.
(g) Low heat of hydration.
(h) High electrical resistivity and low permeability.
2.2.3.2 Benefits of Using Microsilica in Cement or Concrete

Microsilica is considered as a very reactive pozzolanic material because of its extreme fineness and very high amorphous silicon dioxide content. The various advantages or applications of using microsilica as a cementitious material are as follows.

(a) **High Performance Concrete (HPC) containing microsilica** —for highway bridges, parking decks, marine structures and bridge deck overlays which are subjected to constant deterioration caused by rebar corrosion current, abrasion and chemical attack. Silica fume will protect concrete against deicing salts, seawater, road traffic and freeze/thaw cycles. Rebar corrosion activity and concrete deterioration are virtually eliminated, which minimizes maintenance expense.

(b) **High-Strength Concrete (HSC) enhanced with silica fume**—provides architects and engineers with greater design flexibility. Traditionally used in high-rise buildings for the benefit of smaller columns (increasing the usable space) high strength concrete containing silica fume is often used in precast and pre-stressed girders allowing longer spans in structural bridge designs.

(c) **Silica-fume Shotcrete**—delivers greater economy, greater time savings and more efficient use of sprayed concrete. Silica fume produces superior shotcrete for use in rock stabilization; mine tunnel linings, and rehabilitation of deteriorating bridge and marine columns and piles. Greater bonding strength assures outstanding performance of both wet and dry process shotcreting with less rebound loss and thicker applications with each pass of the shotcrete nozzle.

(d) **Oil Well Grouting**—whether used for primary (placement of grout as a hydraulic seal in the well-bore) or secondary applications (remedial operations including leak repairs, splits, closing of depleted zones); the addition of silica fume enables a well to achieve full production potential. Besides producing a blocking effect in the oil well grout that prevents gas migration, it provides these advantages such as (i) improved flow, for easier, more effective application; (ii) dramatically decrease permeability, for better control of gas leakage; and (iii) lightweight

(e) **Repair Products**—silica fume is used in a variety of cementitious repair products. Mortars or grouts modified with silica fume can be tailored to perform in
many different applications—overhead and vertical mortars benefit from silica fume's ability to increase surface adhesion. Silica fume significantly improves cohesiveness making it ideal for use in underwater grouts, decreases permeability in grouts used for post-tensioning applications and increases the resistance to aggressive chemicals.

2.2.3.3 Case Studies

Sellevold and Redjy (1983) reported that there is net decrease in water requirements in concretes containing high concentration of silica fume and water-reducer or superplasticizers which causes the dispersion of cement and silica fume particles and reduces the concentration of contact points between the different grains, resulting in less water requirement to achieve a given consistency. Alshamsi et al. (1993) highlighted the addition of micro-silica to cement pastes or concretes lead to lower workability. Such effect can result in higher water demand to maintain a constant slump. Hence water-reducing admixtures or superplasticizers should be dosage by weight in microsilica in order to keep the water demand as that of control. Rao (2003) studied the influence of silica fume on the workability of mortars and concluded that workability of mortar slightly decreased as the silica fume content increased which is due to the higher specific surface of silica fume, which needs more water for complete hydration and for workability. Mazloom et al. (2004) made high performance concrete containing silica fume. It was observed from the mixes incorporating higher silica fume content tended to require higher dosages of superplasticizer.

Alshami et al. (1993) reported that addition of micro-silica lengthened the setting time of pastes. This was expected since micro-silica replaces part of the OPC reducing the early stiffening potential. While the addition of microsilica (10%) had little effect on setting times, higher percentages produced significant influences. There was 6-20% increase in setting times when OPC was replaced with 20% microsilica. Lohtia and Joshi (1996) concluded from their investigations that superplasticizer causes delay in the setting time, compared to non-silica fume concrete of equal strength, especially when the silicafume content was high. When 15% silicafume was added with superplasticizer, both initial and final setting times were delayed by approximately 1 and 2 h, respectively. Rao (2003) studied the influence of silica fume on the setting time of cement paste. It was observed that initial setting time decreased with the increase in silica fume content. At smaller contents, the setting time of cement paste did
not affect much. However, at higher silica fume contents, the initial setting time was significantly decreased. At 30% silica fume, the initial setting time had been only 30 min. The final setting time seem to be not influenced by the silica fume. The pozzolanic action of silica fume seems to be very active at early hours of hydration. Therefore, he concluded that silica fume contents result in quick setting of cement.

Huang and Feldman (1985) found that the addition of silica fume to mortar resulted in an improved bond between the hydrated cement matrix and sand in the mix, hence increasing strength. This improved bond is due to the conversion of the calcium hydroxide, which tends to form on the surface of aggregate particles, into calcium silicate hydrate due to the presence of reactive silica. Cong et al. (1992) observed that the replacement of cement by silica fume (up to 18%) and the addition of superplasticizer increased the strength of cement paste. According to Wild et al. (1995), this difference in strength development in OPC concrete and silica fume concrete can be attributed to the rapid formation of an inhibiting layer of reaction product preventing further reaction of silica fume with calcium hydroxide beyond 90 days. Behnood and Ziai (2008) designed concrete mixtures to evaluate the effect of silica fume on the compressive strength of the heated and unheated concrete specimens. The replacement of cement by 6 and 10% silica fume increased the 28-day compressive strength approximately by 19 and 25% respectively. They concluded that concrete containing silica fume had significantly higher strength than that of OPC concrete. Elsayed (2011) studied the influence of water permeability and strength of concrete by incorporating in to concrete at levels of 5%, 10% and 15% for silica fume by weight of cement. The lowest measured water permeability was at 10% silica fume and also the highest compressive strength was at 10% replacement of OPC by silica fume which reduced with further increase in the silica fume content.

Perraton et al. (1988) studied the effect of silica fume on the chloride permeability of concretes. They observed significant reduction in the chloride-ion diffusion in silica fume concretes which further decreased with increasing addition of silica fume. Main reason that could be attributed to reduced permeability is that addition of silica fume cause considerable pore refinement i.e. transformation of bigger pores into smaller one due to their pozzolanic reaction concurrent with cement hydration. By this process the permeability of hydrated cement paste as well as porosity of the transition zone between cement paste and aggregate are reduced. Soroushian et al. (1995) reported a
75% reduction in the permeability to chloride ions when polypropylene fibres were used along with silica fume in a portland cement matrix. The decrease in the coefficient of chloride diffusion was 98% when silica fume was added to the glass fibre reinforced mortar. The positive effects of silica fume additions were attributed to the increase in density and reduction in capillary porosity caused by reaction products such as calcium silicates and calcium aluminates, which change the material microstructure.

Sellevold and Nilsen (1987) reported field studies of concretes with and without 15% silica fume. After 20 years' exposure to ground water containing 4 g/l sulfate and 2.5 - 7.0 pH, the performance of the silica fume concrete was found equal to that of the concretes made with sulfate-resisting Portland cement, even though the water/cementitious materials ratio was higher for silica fume concrete (0.62) than for control (0.50). According to ACI Committee 234 (1995), the effect of silica fume on sulfate resistance is due more to the reduction in permeability than to dilution of the C₃A content because of the relatively low doses of silica fume used in practice. Wee et al. (2000) also showed that silica fume, at replacement levels of 5 and 10% by mass of OPC plays a key role in resisting sodium sulfate attack, indicating no signs of spalling after about 1 year of exposure in 5% sodium sulfate solution.

Hooton (1993) studied the influence of silica fume on the expansion of mortars made with high-alkali cement up to the age of 365 days. Expansions were reduced with increasing replacement of silica fume. It was concluded that mortars made with 10, 15 and 20% silica fume met the ASTM expansion limit of 0.020% at the age of 14 days.

Huang and Feldman (1985) studied the influence of silica fume on the microstructure development in cement mortars containing 0, 10 and 30% silicafume. Compressive strength, Ca(OH)₂ and non-evaporable water contents and pore structure distribution were monitored up to 180 days. Silica fume reacts with most of the Ca(OH)₂ formed during hydration within 28 days and improves the compressive strength of mortar. In addition it affects the pore size distribution of mortars by reacting with Ca(OH)₂ formed which was analysed by SEM analysis.

Jelica et al. (2007) studied the effect of silica fume additions on durability of portland cement mortars exposed to magnesium sulfate attack which were evaluated by differential thermal analysis (DTA) and by X-ray diffraction (XRD) analysis. The changes in the length of the mortars due to expansion as well as the elasticity modulus
and mechanical strength loss as a function of silica fume replacement were determined. The results showed that the replacement is having a positive effect on magnesium sulphate resistance which shows lower expansion than the control mortar due to the absence of gypsum and ettringite, detected by the XRD analysis.

2.2.4 RICE HUSK ASH

Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. Current rice production in the world is more than 700 million tons. Rice husk constitutes about 20% of the weight of rice. It contains about 50% cellulose, 25-30% lignin, and 15-20% of silica (Rafat Siddique and Mohammad Iqbal Khan, 2011). Traditionally, rice husk has been considered a waste material and has generally been disposed of by dumping or burning, although some has been used as a low-grade fuel. Rice husk ash (RHA) is generated by burning rice husk. On burning cellulose and lignin are removed leaving behind silica ash. The controlled temperature and environment of burning yields better quality of rice-husk ash as its particle size and specific surface area are dependent on burning condition. The ash produced by controlled burning of the rice husk between 550°C and 700°C incinerating temperature for 1 hour transforms the silica content of the ash into amorphous phase. The reactivity of amorphous silica is directly proportional to the specific surface area of ash. The ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement.

2.2.4.1 Environmental Benefits of Using Rice Husk Ash

Rice husk ash is also used and has several environmental advantages over other choices:

(a) it's a renewable, agricultural waste product,
(b) is a product of combustion for heat recovery,
(c) has low heavy-metal content,
(d) works as a pozzolan
(e) helps to the disposal of waste materials and
(f) to reduce carbon dioxide emissions.
2.2.4.2 Benefits of Using Rice Husk Ash in Cement or Concrete

Rice-husk ash is a very fine pozzolanic material. The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages such as

(a) Improved strength
(b) Enhanced durability properties
(c) Reduced materials costs due to cement savings

Rice husk ash is used in following applications:

(a) Blended cements
(b) Green concrete
(c) High performance concrete
(d) Refractory
(e) Roofing shingles
(f) Ceramic glaze
(g) Insulator
(h) Waterproofing chemicals
(i) Oil spill absorbent

2.2.4.3 Case Studies

Ganesan et al. (2008) reported the effect of cement replacement with RHA on the consistency and setting times of cement. Percentages of cement replacement were 0, 5, 10, 15, 20, 25, 30, and 35. It was observed that up to 15%, RHA level increased the initial setting time. At 20, 25, 30 and 35%, there was reduction in initial setting time. The initial setting time measured for RHA blended cements up to 35% was higher than that of control OPC. On the other hand, the final setting time decreased with the increase in RHA up to 35%. Sensale et al. (2008) investigated the influence of partial replacements of Portland cement by rice-husk ash (RHA) on setting times of cement paste. Pastes with water/binder ratio 0.30 and substitutions of 5 and 10% cement by RHA were used and observed that setting times decreased with increase in RHA content.
Inclusion of RHA as partial replacement of cement enhances the compressive strength of concrete but the optimum replacement level of OPC by RHA to give maximum long term strength enhancement has been reported between 10% up to 30%. All these replacement levels of RHA are in percentage by weight of the total binder material. Rahman (1987) determined the compressive strength of various mix proportions of sand, cement and rice husk ash (RHA) for use in sandcrete block at the age of 7, 28 and 60 days. It is evident from the results that up to 40% RHA could be added as a partial replacement for cement without any significant change in compressive strength at 60 days. Ikpong and Okpala (1992) studied the effect of replacement of cement (0, 20, 25 and 30%) with RHA on the compressive strength of concrete and concluded that compressive strength continued to increase with age for each of the mixes. The control mix (0% RHA) attained a higher strength than the OPC/RHA mixes at all ages. Mahmud et al. (1996) reported 15% cement replacement by RHA as an optimal level for achieving maximum strength. Zhang et al. (1996) suggested 10% RHA replacement exhibited upper strength than control OPC at all ages. Tashima et al. (2005) investigated the influence of 0, 5, and 10% RHA as partial replacement of cement on the compressive strength of concrete. Addition of RHA caused an increase in compressive strength due to the pozzolanic action of RHA and compressive strength increased with age; and maximum increase (25%) in strength was found to be with 5% RHA. Agarwal (2006) studied the accelerated pozzolanic activity of rice husk ash. The RHA was collected from paper mill using rice husk as fuel (90.52% SiO₂). The pozzolanic activity of RHA was determined by compressive strength of mortar cubes cured in water at 7 and 28 days and observed the increase in the compressive strength. Ganesan et al. (2008) concluded that concrete containing 15% of RHA showed an utmost compressive strength and loss at elevated content more than 15%. Ramezanianpour et al. (2009) investigated the compressive strength of concrete mixtures containing rich husk ash (RHA) up to the age of 90 days. Concrete mixtures were made with 0, 7, 10 and 15% RHA as partial replacement of cement and concluded that RHA concrete achieved higher compressive strengths up to 90 days when compared with the control concrete. Recent study on the use of RHA as a construction material has been reported by Jayasankar et al. (2010), Nargale et al. (2012) and Sandesh et al. (2012), where the amount of replacement varies from 0 to 20% without varying the grade of the Ordinary Portland Cement (OPC).
Zhang and Malhotra (1996) studied the chloride-ion penetration resistance of concretes made with 10% RHA and 10% silica fume (SF). It can be seen that use of RHA and SF has drastically reduced the chloride-ion penetration at both the ages. These values were less than 1000. As per ASTM C1202, when charge passed through concrete is less than 1000 C, the concrete has very high resistance to chloride ion penetration. Anwar et al. (2001) and Nahdi et al. (2003) concluded from their investigations that there are significant reductions in chloride ions permeability from moderate rating to low and very low ratings due to replacing of OPC with RHA. Coutinho (2003) investigated the rapid chloride permeability of concrete made with RHA (10, 15, and 20%) as partial replacement of cement and when using controlled permeability formwork (CPF). Controlled permeability formwork (CPF) is the technique developed for directly improving the concrete surface zone. Concluded that inclusion of RHA significantly reduced the charge passed. Furthermore, when CPF was used, it greatly reduced the permeability of concrete mixtures. The results of the study made by Sakr (2006) revealed that concrete mixed with RHA had good resistance to sulfate attack which is one of the important aspects of durability. Saraswathy and Song (2007) studied the effect of rice husk ash (RHA) on the chloride permeability of concrete and observed that replacement of rice husk ash drastically reduced coulomb values. As the replacement level increased, the chloride penetration decreased. As per ASTM C1202, RHA reduced the rapid chloride penetrability of concrete from a low to very low ratings from higher to lower replacement levels.

Ganesan et al. (2008) examined the influence of RHA on the chloride permeability of concrete. Cement was replaced with 0, 5, 10, 15, 20, 25, 30 and 35% RHA. It was observed that the chloride permeability reduced considerably by partial replacement of OPC with RHA up to 30%. Chindaprasirt et al. (2008) determined the chloride penetration resistance of blended portland cement mortar containing ground rice husk ash (RHA) at the age of 28 days. Ordinary Portland Cement (OPC) was partially replaced with 20 and 40% RHA by weight of cementitious materials. RHA had silica content of 93.2%. The 100 x 50 mm cylinders were tested at the age of 28 days for rapid chloride penetration test (RCPT) in accordance with ASTM C1202. The charge passed was substantially reduced with incorporation of RHA as compared to 7450 C of normal OPC mortar. The incorporation of 20 and 40% RHA reduced the charge passed to 750 and 200 C at 20 and 40% replacement levels. Ramezanianpour
et al. (2009) investigated the influence of RHA on the chloride ion penetration of concrete up the age of 90 days and observed that RHA drastically enhanced resistance to chloride penetration compared to control concrete on average, around 4–5 times higher for the 15% RHA. At 7 days, the control concrete showed the highest value of 6189 C while the charge passed through the 15% RHA concrete was 1749 C.

Mehta (1992) has indicated that the activity of RHA was reduced. However, in the present case, increase in activity from 10 to 48% was observed. It is possible that a fraction of RHA present is showing the peaks of cristobalite and tridymite, which, on grinding, has no significant effect on the activity. The X-ray diffraction of RHA shows a peak of cristobalite and tridymite. Cizer et al. (2006) carried out the XRD analysis of RHA and indicated its amorphous phase with a broad band between 15 and 30, 2θ°. It contains certain amount of crystalline silica in the form of cristobalite and tridymite. Chindapaarsirt et al. (2008) examined the SEM of ground rice husk ash which revealed that the rice husk ash maintains its cellular structure. After being ground, RHA consists of very irregular-shaped particles with porous cellular surface.

2.2.5 Some Other Supplementary Cementing Materials

**Metakaolin:** Metakaolin (MK) is a pozzolanic material. It is a dehydroxylated form of the clay mineral kaolinite. It is obtained by calcination of kaolinitic clay at a temperature between 500°C and 800°C. Between 100°C and 200°C, clay minerals lose most of their adsorbed water. Between 500°C and 800°C kaolinite becomes calcined by losing water through dehydroxilization. The raw material input in the manufacture of metakaolin (Al₂Si₂O₇) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a common mineral, hydrated aluminum disilicate, the most common constituent of kaolin.

Except diatomaceous earth, all natural pozzolans are derived from volcanic rocks and minerals. During explosive volcanic eruptions quick cooling of the magma, which is composed mainly of alumino silicates results in the formation of glass or vitreous phases with disordered structure.
Volcanic glasses: Santorini Earth of Greece, Bacoli Pozzolan of Italy, and Shirasu Pozzolan of Japan are examples of pozzolanic materials which derive their lime-reactivity characteristic mainly from the unaltered aluminosilicate glass.

Volcanic tuffs: Pozzolans of Segni-Latium (Italy), and trass of Rheinland and Bavaria (Germany), represent typical volcanic tuffs.

Diatomaceous earth: This group of pozzolans is characterized by materials of organic origin. Diatomite is hydrated amorphous silica which is composed of skeletal shells from the cell walls of many varieties of microscopic aquatic algae. The largest known deposit is in California.

Calcined clays or shales: Clay and shales will not show appreciable reactivity with lime unless the crystal structures of the clay minerals present are destroyed by heat treatment. Temperatures on the order of 600°C to 900°C, ion kilns are required for this purpose. The pozzolanic activity of the product is due mainly to the formation of an amorphous or disordered aluminosilicate structure as a result of the thermal treatment. Calcined shale or clay used at higher percentages by mass.

Raghuprasad et al. (2005) from their investigations concluded that the initial rate of gain of strength of blended cement concrete like PSC and PPC is lower which is mainly due to the slow pozzolanic reaction, but the strength development continues for longer periods beyond 28 days.

2.3 CHEMICAL ADMIXTURES

Admixtures are those ingredients in concrete other than portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. A wide range of admixtures are available. The table below provides a list of common types of chemical admixtures. The effectiveness of an admixture in concrete depends upon many factors including cementitious materials properties, water content, aggregate properties, concrete materials proportions, mixing time and intensity, and temperature.
Table 2.1 Brief Description of Common Types of Chemical Admixtures

<table>
<thead>
<tr>
<th>Type of Admixture</th>
<th>Standard Specifications</th>
<th>Desired Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-entraining admixture (AEA)</td>
<td>ASTM C260 and C233 (AASHTO M 154 and T 157).</td>
<td>To stabilize microscopic bubbles in concrete, which can provide freeze-thaw resistance and improve resistance to deicer salt scaling.</td>
</tr>
<tr>
<td>Water reducing admixture (WR)</td>
<td>ASTM C494 (AASHTO M 194)</td>
<td>Reduce the water content by 5 to 10%, while maintaining slump characteristics.</td>
</tr>
<tr>
<td>Mid-range water reducer (MRWR)</td>
<td>ASTM C494 (AASHTO M 194)</td>
<td>Reduce the water content by 6% to 12%, while maintaining slump and avoiding retardation.</td>
</tr>
<tr>
<td>High-range water reducer (HRWR)</td>
<td>ASTM C494 (AASHTO M 194), ASTM C1017</td>
<td>Reduce the water content by 12% to 30%, while maintaining slump.</td>
</tr>
<tr>
<td>Retarding admixture</td>
<td>ASTM C494 (AASHTO M 194)</td>
<td>To decrease the rate of hydration of cement.</td>
</tr>
<tr>
<td>Accelerating admixture</td>
<td>ASTM C494 (AASHTO M 194)</td>
<td>To increase the rate of hydration of cement.</td>
</tr>
<tr>
<td>Corrosion inhibitors</td>
<td>ASTM C1582</td>
<td>Minimize steel reinforcement corrosion.</td>
</tr>
</tbody>
</table>

Superplasticizers

The use of superplasticizers (high range water reducer) has become a quite common practice. This class of water reducers was originally developed in Japan and Germany in the early 1960s; they were introduced in the United States in the mid-1970s. (U.S Department of Transportation, 1990)

Superplasticizers are linear polymers containing sulfonic acid groups attached to the polymer backbone at regular intervals (Verbeck 1968). Most of the commercial formulations belong to one of four families:

- Sulfonated melamine-formaldehyde condensates (SMF)
- Sulfonated naphthalene-formaldehyde condensates (SNF)
- Modified lignosulfonates (MLS)
- Polycarboxylate derivatives
The sulfonic acid groups are responsible for neutralizing the surface charges on the cement particles and causing dispersion, thus releasing the water tied up in the cement particle agglomerations and thereafter reducing the viscosity of the paste and concrete (Mindess and Young, 1981).

ASTM C 494 was modified to include high-range water-reducing admixtures in the edition published in July 1980. The admixtures were designated Type F water-reducing, high range admixtures and Type G water-reducing, high-range, and retarding admixtures (Mielenz, 1984).

**Effect of Superplasticizers on Concrete Properties:** The main purpose of using superplasticizers is to produce flowing concrete with very high slump in the range of 7-9 inches (175-225 mm) to be used in heavily reinforced structures and in placements where adequate consolidation by vibration cannot be readily achieved. The other major application is the production of high-strength concrete at w/c's ranging from 0.3 to 0.4 (Ramachandran and Malhotra, 1984).

The capability of superplasticizers to reduce water requirements 12-25% without affecting the workability leads to production of high-strength concrete and lower permeability. Compressive strengths greater than 14000 psi (96.5 MPa) at 28 days have been attained (Admixtures and ground slag, 1990).

### 2.4 SUMMING UP

The optimum combination of materials will vary for different performance requirements and type of supplementary cementitious materials. As the ready mixed concrete producer, with the knowledge of the locally available materials, can establish the mixture proportions for the required performance similar is the case with the usage of different mineral and chemical admixtures. Perspective restrictions can inhibit optimization and economy in all aspects, while several enhancements to concrete properties are discussed above which are investigated by several researchers. These properties are not mutually exclusive and the combination should be proportioned for the most critical performance requirements for the job with the available materials.

The literature review reveals that a lot of work has been done to find the various properties of concrete and mortar with the partial replacement of cement by different admixtures which shows the importance of increased practice of admixtures but there is
a lack of established work to find out which combination gives better results when two different types of cements i.e., ordinary portland cement and portland slag cement are used. Hence experiments have been planned to investigate the various properties and find out the best combination for the tradition of different admixtures in an effective manner in the cement industry.
CHAPTER III

SCOPE AND OBJECTIVES OF THE PRESENT INVESTIGATION

In view of the growing importance of using locally available supplementary cementing materials, in the present investigation an attempt has been made to achieve the following objectives:

1. To assess the effect of partial replacement of different waste materials on weight basis of both the Portland Slag Cement and the Ordinary Portland Cement with different mineral admixtures like Fly Ash, Ground Granulated Blast furnace Slag, Microsilica, Rice Husk Ash when they are mixed with superplasticizer and without superplasticizer which is a chemical admixture, on various mechanical properties such as initial and final setting times, soundness.

2. To examine the effects of these substances with different dosages like 5%, 10% and 15% replacement of cement by weight in the mortar cubes on short term and long term strength development by finding the compressive strength values at different ages i.e., 3 days, 7 days, 28 days, 90 days and 365 days.

3. To find the strengths of cement mortar cubes after conducting various durability tests like Acid Test, Alkaline Test, Sulphate Test and Rapid Chloride Permeability Test.

4. To study the micro level structure configuration by generating high resolution images of the various mortar cubes prepared with the replacement of different cement samples with different types of admixtures by using Scanning Electron Microscopy (SEM).

5. To identify the chemical compounds formed in different combinations of cement mortar by assessing the spatial variations in the chemical compositions which was done by using X-Ray Diffractive studies (XRD) by correlating the results obtained for finding the predominant elements found by using standard Joint Committee on Powder Diffraction Standards (JCPDS) data in Energy Dispersive X-Ray Spectroscopy (EDS).

6. To identify the best combinations of supplementary cementing materials used, with ordinary portland cement and portland slag cement which is most economic and which can be considered as optimum dosage of cement replacement for that particular admixture.
7. To identify which cement is giving better performance and identify best admixture with the combination of that cement for better percentage replacement out of 5%, 10% and 15%. 
CHAPTER IV
MATERIALS AND EXPERIMENTAL INVESTIGATIONS

4.1 GENERAL

The physico-chemical properties of cement, sand and water used in the investigation were analyzed based on and also the standard experimental procedure laid down in the standard codes, like IS, ASTM and BS codes. These standard experimental procedures were adopted for the determination of normal consistency, initial and final setting times, soundness of cement and compressive strength of cement mortar cubes, durability tests and special tests.

4.2 MATERIALS

The materials used in the experimental investigation include:

1. (a) Cement: Portland Slag Cement (PSC)
   (b) Cement: Ordinary Portland Cement (OPC)
2. Fine aggregate: Sand
3. Water
4. Mineral Admixtures
   (a) Fly Ash (FA)
   (b) Ground Granulated Blast Furnace Slag (GGBS)
   (c) Microsilica (MS)
   (d) Rice Husk Ash (RHA)
5. Chemical Admixture – Superplasticizer (SP)

The properties of these materials are given in the following sub-sections.

4.2.1 CEMENT

Initial experiments like initial setting time, final setting time, soundness and compressive strength test on mortar cubes were conducted on Portland Slag Cement and Ordinary Portland Cement with regard to various mineral and chemical admixtures. Portland Slag Cement and Ordinary Portland Cement were used in the present investigation. The chemical composition of the cement is presented in Table 4.1 and the
percentage composition of the major compounds (known as the Bogue compounds) present in the cement are presented in Table 4.2 (Bogue and Lerch, 1934).

Table 4.1 Chemical Composition of Cement

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Oxide</th>
<th>Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CaO</td>
<td>60-66</td>
</tr>
<tr>
<td>2</td>
<td>SiO₂</td>
<td>19-24</td>
</tr>
<tr>
<td>3</td>
<td>Al₂O₃</td>
<td>03-08</td>
</tr>
<tr>
<td>4</td>
<td>Fe₂O₃</td>
<td>01-05</td>
</tr>
<tr>
<td>5</td>
<td>SO₃</td>
<td>01-04</td>
</tr>
<tr>
<td>6</td>
<td>MgO</td>
<td>00-05</td>
</tr>
<tr>
<td>7</td>
<td>K₂O</td>
<td>00-02</td>
</tr>
<tr>
<td>8</td>
<td>Na₂O</td>
<td>00-01</td>
</tr>
</tbody>
</table>

Table 4.2 Percentage Composition of the Major Compounds Present in the Cement

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the Compounds</th>
<th>Conversion Formulae</th>
<th>Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tricalcium silicate, 3CaO·SiO₂</td>
<td>4.07 (CaO) -7.60 (SiO₂) -6.72 (Al₂O₃) -1.43 (Fe₂O₃) -2.85 (SO₃)</td>
<td>50-70</td>
</tr>
<tr>
<td>2</td>
<td>Dicalcium silicate, 2CaO·SiO₂</td>
<td>2.87 (SiO₂) -0.754(3CaO·SiO₂)</td>
<td>15-30</td>
</tr>
<tr>
<td>3</td>
<td>Tricalcium aluminate, 3 CaO·Al₂O₃</td>
<td>2.65 (Al₂O₃) -1.69 (Fe₂O₃)</td>
<td>05-10</td>
</tr>
<tr>
<td>4</td>
<td>Tetracalcium alumino ferrite, 4CaO·Al₂O₃·Fe₂O₃</td>
<td>3.04 (Fe₂O₃)</td>
<td>05-15</td>
</tr>
</tbody>
</table>

4.2.1.1 Portland Slag Cement

Portland slag cement is obtained by mixing blast furnace slag, cement clinker and gypsum and grinding them together to get intimately mixed cement. The quantity of slag varies from 30-70%. The gain of strength of PSC is somewhat slower than OPC in the early ages. Cement used in the present investigation is Ultratech.
Ordinary Portland Cement

Ordinary portland cement is the most common type of cement in general use around the world, used as a basic ingredient of concrete and mortar. Ordinary portland cement is graded as 33, 43, 53 which indicated that the compressive strength of cement after 28 days when tested as per IS : 4031-1988 must be 33Mpa, 43Mpa and 53 Mpa respectively. In the case of other cements also, they must gain a particular strength after a specified period of time. Cement used in the present study is Zuari 43 Grade. The compressive strength of cement when tested as per IS code shall be minimum 43 Mpa.

The physical and chemical properties of the two types of cements used in the present investigation are presented in the Table 4.3 and Table 4.4 respectively.

**Table 4.3 Physical Properties of Portland Slag Cement and Ordinary Portland Cement as per IS Code Specifications**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Physical Property</th>
<th>Portland Slag Cement</th>
<th>Ordinary Portland Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>3.01</td>
<td>3.15</td>
</tr>
<tr>
<td>2</td>
<td>Normal consistency</td>
<td>35%</td>
<td>Not specified</td>
</tr>
<tr>
<td>3</td>
<td>Setting times (minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Initial</td>
<td></td>
<td>133</td>
<td>Not less than 30</td>
</tr>
<tr>
<td>b) Final</td>
<td></td>
<td>217</td>
<td>Not more than 600</td>
</tr>
<tr>
<td>4</td>
<td>Compressive strength (MPa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) 3 days</td>
<td></td>
<td>22.50</td>
<td>Not less than 16</td>
</tr>
<tr>
<td>b) 7 days</td>
<td></td>
<td>26.20</td>
<td>Not less than 22</td>
</tr>
<tr>
<td>c) 28 days</td>
<td></td>
<td>36.40</td>
<td>Not less than 33</td>
</tr>
</tbody>
</table>
Table 4.4 Chemical Properties of PSC and OPC Specified by IS Code

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Magnesia (% by mass)</td>
<td>&lt;8.0</td>
<td>&lt;6</td>
</tr>
<tr>
<td>2</td>
<td>Sulphur trioxide (% by mass)</td>
<td>&lt;3.0</td>
<td>&lt;3</td>
</tr>
<tr>
<td>3</td>
<td>Sulphide sulphur</td>
<td>&lt;1.5</td>
<td>0.6-1.02</td>
</tr>
<tr>
<td>4</td>
<td>Total loss on ignition</td>
<td>&lt;5.0</td>
<td>&lt;5</td>
</tr>
<tr>
<td>5</td>
<td>Insoluble residue</td>
<td>&lt;4.0</td>
<td>&lt;3</td>
</tr>
<tr>
<td>6</td>
<td>Chloride</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>

4.2.2 FINE AGGREGATE: SAND

The sand used throughout the experimental work was obtained from the river Swarnamukhi near Tirupati, Chittoor district, Andhra Pradesh. This type of sand was used by the many of researchers as an ingredient in cement mortar (Raghu Prasad and Appa Rao, 1997). According to IS 650:1991, the sand used in cement mortar should conform to the following specifications.

(a) Standard sand shall be of quartz, light grey or whitish variety. It shall be free from silt. The grains shall be angular, the shape of grains approximating to spherical form, elongated and flattened grains being present only in very small or negligible quantities.

(b) The standard sand shall (100%) pass through 2 mm IS sieve and shall be (100%) retained on 90 - micron IS sieve with the following particle size distribution.

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller than 2 mm and greater than 1 mm</td>
<td>33.3</td>
</tr>
<tr>
<td>Smaller than 1 mm and greater than 500 microns</td>
<td>33.3</td>
</tr>
<tr>
<td>Below 500 microns but greater than 90 microns</td>
<td>33.3</td>
</tr>
</tbody>
</table>

(The sieves shall conform to IS 460 (Part 1): 1985)
(c) The standard sand shall be free from organic impurities. The loss of mass on extraction with hot hydrochloric acid 1.16 (conforming to IS 265: 1987) shall not be more than 0.25 % when tested as per the procedure given below.

**Procedure:** The sand shall be dried at 100°C for one hour. 2 gm of sand shall be transferred to porcelain dish and 20 ml of hydrochloric acid and 20 ml of distilled water added to it. This shall be heated on a water bath for one hour. It shall then be filtered, washed well with hot water, dried and ignited in a covered crucible. The mass of the residue shall be determined and loss in mass calculated.

The specific particle size composition of the sand was prepared as per the IS: 650 (1991) and IS: 383 (1970). Sand was thoroughly washed with tap water to remove impurities like decayed vegetable matter, humus, organic matter and deleterious materials like clay, fine silt and fine dust and was oven dried for 24 hours and cooled to room temperature. This sand was used for the experimental work. Deleterious substances are likely to interfere with the process of hydration, prevent the effective bond between the fine aggregate and matrix (Hooton, 1993). These impurities most probably reduce the strength and durability of the cement mortar and hence care was taken for the sand used in the investigation.

The organic matter will interfere with the setting action of cement and also interfere with the bond characteristics with the fine aggregates. The presence of organic matter will also result in entrainment of air voids in the mortar and reduces its strength. At the same time excessive silt or clay contained in the fine or course aggregate may result in increased shrinkage or increased permeability in addition to poor bond characteristics (Komar, 1987 and Duggal, 1997).

The properties of sand were analysed in accordance with the procedures laid down in IS 2386 (Part I and Part II) : 1963 and were presented in Table 4.5.
Table 4.5 Properties of Sand

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Unit</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td></td>
<td>2.64</td>
</tr>
<tr>
<td>2</td>
<td>Bulk density</td>
<td>kN/m³</td>
<td>15.54</td>
</tr>
<tr>
<td>3</td>
<td>Fineness modulus before sieving</td>
<td></td>
<td>2.72</td>
</tr>
<tr>
<td>4</td>
<td>Particle size variation</td>
<td></td>
<td>90μ to 2.0 mm</td>
</tr>
<tr>
<td>5</td>
<td>Loss of weight with concentrated Hydrochloric acid</td>
<td>%</td>
<td>&lt;0.25</td>
</tr>
</tbody>
</table>

4.2.3 WATER

The water used for the present investigation was tap water available in the laboratory and the same was analyzed according to the standard methods for the examination of water. (APHA 1994) and the values are presented in Table 4.6. The results shows potable water standards and hence used in the present investigation.

Table 4.6 Characteristics of water (All values in mg/l except pH)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>Units</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td>-</td>
<td>6.8</td>
</tr>
<tr>
<td>2</td>
<td>Total dissolved solids</td>
<td>mg/l</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>Alkalinity</td>
<td>mg/l</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>Acidity</td>
<td>mg/l</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Hardness</td>
<td>mg/l</td>
<td>140</td>
</tr>
<tr>
<td>6</td>
<td>Sulphates</td>
<td>mg/l</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Chlorides</td>
<td>mg/l</td>
<td>65</td>
</tr>
</tbody>
</table>

4.2.4 MINERAL ADMIXTURES

4.2.4.1 Fly Ash

All Indian fly ashes tested at CANMET correspond to the category of ASTM class C fly ashes. Typically all fly ashes had very low lime (CaO < 1.5%), low alkali (Na₂O<1.34%) and Sulphur (SO₂<0.01%) contents. The physical properties of most of the fly ashes are found to be excellent. The workability of the fresh concrete made with cement and fly ash are found to be the best. The additional binder produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages (less than 90
days) will ultimately exceed the strength of straight cement concrete mixes. All concretes have excellent resistance to chloride ion penetration as determined by ASTM C 1202 (1997) with coulomb values below 1000 in each case. (Rafat Siddique and Mohammad Iqbal Khan, 2011).

The primary difference between Class C and Class F fly ash is the chemical composition of the ash itself. While Class F fly ash is highly pozzolanic, meaning that it reacts with excess lime generated in the hydration of portland cement, Class C fly ash is pozzolanic and also can be self cementing. ASTM C618 (1978) requires that Class F fly ash contain at least 70% pozzolanic compounds (silica oxide, alumina oxide, and iron oxide), while Class C fly ashes have between 50% and 70% of these compounds. Typically, Class C fly ash also contains significant amounts of calcium oxide - over 20%. Most Class F fly ash contains little calcium oxide; however, some Class F fly ash sources may contain intermediate levels (8% to 16%) of calcium oxide. While both classes of fly ash greatly reduce concrete permeability as compared to the cement only mixes, Class F tends to give proportionately greater permeability reduction. Due to the higher levels of pozzolanic compounds, Class F fly ash mitigates against sulfate attack, alkali silica reaction, corrosion of reinforcement, and chemical attack.

Fly ash (Class F type) having specific gravity 2.43 procured from Rayalaseema Thermal Power Plant (RTPP) at Kalamalla near Muddanur of Kadapa district, Andhra Pradesh was used in the present investigation. It is conformed to grade1 of IS 3812:1981. The physical and chemical properties of this fly ash are given in the Table 4.7(a) and 4.7(b).

**Table 4.7(a) Physical Characteristics of Fly Ash**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Physical Characteristics</th>
<th>Percentage IS 3812:1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silica SiO₂</td>
<td>49 – 67</td>
</tr>
<tr>
<td>2</td>
<td>Alumina Al₂O₃</td>
<td>16 – 28</td>
</tr>
<tr>
<td>3</td>
<td>Iron oxide Fe₂O₃</td>
<td>4 – 10</td>
</tr>
<tr>
<td>4</td>
<td>Lime CaO</td>
<td>0.7 – 3.6</td>
</tr>
<tr>
<td>5</td>
<td>Magnesia MgO</td>
<td>0.3 – 2.6</td>
</tr>
<tr>
<td>6</td>
<td>Sulphur trioxide SO₃</td>
<td>0.1 – 2.1</td>
</tr>
<tr>
<td>7</td>
<td>Loss on ignition</td>
<td>0.4 – 0.9</td>
</tr>
<tr>
<td>8</td>
<td>Surface area m²/kg</td>
<td>230 – 600</td>
</tr>
</tbody>
</table>
4.2.4.2 Ground Granulated Blast Furnace Slag

The granulated slag when finely ground and combined with portland cement has been found to have excellent cementitious properties. GGBS has an inherent ability to reduce heat evolved during exothermic reaction of cement and water. GGBS can be used as a direct replacement for cement on one to one basis by weight. Replacement rates for GGBS vary up to 85%. Generally 50% is used in most applications. Higher replacement rates up to 85% are used in specialist applications such as in aggressive environments and to reduce heat of hydration. GGBS can be used at replacement levels of 70% in lean mix concrete (Rafat Siddique and Mohammad Iqbal Khan, 2011).

Ground Granulated Blast Furnace Slag obtained from Lanco Steel Plant, Srikalahasti, Andhra Pradesh was used as a replacing material in the present investigation. The various physical and chemical properties are presented in the Table 4.8.

Table 4.8(a) Physical Characteristics of Ground Granulated Blast Furnace Slag

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Physical Characteristics</th>
<th>Properties of Slag used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>2.91</td>
</tr>
<tr>
<td>2</td>
<td>Fineness m³/kg</td>
<td>330</td>
</tr>
<tr>
<td>3</td>
<td>Glass content percent</td>
<td>93</td>
</tr>
<tr>
<td>4</td>
<td>Bulk density kg/m³</td>
<td>1100</td>
</tr>
<tr>
<td>5</td>
<td>Colour</td>
<td>Dull white</td>
</tr>
</tbody>
</table>
Table 4.8(b)  Chemical Composition of Ground Granulated Blast Furnace Slag

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SiO₂</td>
<td>32-42</td>
<td>33.2</td>
</tr>
<tr>
<td>2</td>
<td>Al₂O₃</td>
<td>7-16</td>
<td>13.3</td>
</tr>
<tr>
<td>3</td>
<td>CaO</td>
<td>32-45</td>
<td>41.0</td>
</tr>
<tr>
<td>4</td>
<td>Fe₂O₃</td>
<td>0.1-1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>MgO</td>
<td>5-15</td>
<td>11.6</td>
</tr>
<tr>
<td>6</td>
<td>SO₃</td>
<td>2.5 max</td>
<td>1.0</td>
</tr>
<tr>
<td>7</td>
<td>CaO/ SiO₂</td>
<td>1.4 max</td>
<td>1.23</td>
</tr>
<tr>
<td>8</td>
<td>Loss on ignition</td>
<td>3 max</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4.2.4.3 Microsilica

The use of the microsilica was limited to cement replacement due to its high pozzolanic reactivity. But, now a days microsilica has become additional cementitious component because of its increased performance both in fresh and hardened states and is used in the development of high strength concretes. Generally, microsilica concrete is used in the construction of lengthy bridges, tunnels, hydraulic dams and nuclear reactors due to its special qualities (Rafiat Siddique and Mohammad Iqbal Khan, 2011).

Microsilica has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. Addition of microsilica to mortar or concrete improves the durability through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to various attacks. Improvement in durability will also improve the ability of blended concrete in protecting the embedded steel from corrosion. Hence microsilica is considered as the best out of different admixtures used.

Microsilica 920-D used in the present study was obtained from Elkem India Pvt. Ltd., Mumbai. The properties of microsilica are presented in Table 4.9.
Table 4.9 Properties of Microsilica 920-D

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Specification</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SiO₂</td>
<td>% Min 85.0</td>
<td>89.2</td>
</tr>
<tr>
<td>2</td>
<td>Moisture content</td>
<td>% Max 3.0</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>Loss on ignition</td>
<td>% Max 6.0</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>45 micron</td>
<td>% Max 10</td>
<td>8.0</td>
</tr>
<tr>
<td>5</td>
<td>Bulk density</td>
<td>500-700 Kg/m³</td>
<td>550</td>
</tr>
</tbody>
</table>

4.2.4.4 Rice Husk Ash

Rice Husk, from the locally grown mixed varieties was produced from rice mills in Tirupati locality was collected and used. The rice husk procured thus was incinerated in open air and the ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement. The physical and chemical properties are presented in Table 4.10.

Table 4.10 Physical and Chemical Properties of Rice Husk Ash

Physical Properties of Rice Husk Ash

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Properties</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Variety</td>
<td>Mixed</td>
</tr>
<tr>
<td>2</td>
<td>Calorific value</td>
<td>3350 Kcal/kg</td>
</tr>
<tr>
<td>3</td>
<td>Specific gravity</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Loss on ignition</td>
<td>3.6%</td>
</tr>
<tr>
<td>5</td>
<td>Burning</td>
<td>Open</td>
</tr>
<tr>
<td>6</td>
<td>Fineness Blains</td>
<td>16000 cm²/gm</td>
</tr>
</tbody>
</table>

Chemical Constituent of Rice Husk Ash

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Constituent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SiO₂</td>
<td>93.2</td>
</tr>
<tr>
<td>2</td>
<td>Al₂O₃</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>Fe₂O₃</td>
<td>0.45</td>
</tr>
<tr>
<td>4</td>
<td>MgO</td>
<td>0.40</td>
</tr>
<tr>
<td>5</td>
<td>CaO</td>
<td>3.15</td>
</tr>
<tr>
<td>6</td>
<td>KO</td>
<td>1.6</td>
</tr>
</tbody>
</table>
4.2.5 Chemical Admixture-Superplasticizer

The superplasticizer utilized was supplied by internationally reputed admixtures manufactures. Conplast SP 430 was manufactured by Fosroc. Conplast SP 430 is based as sulphonated naphthalene formaldehyde superplasticizer. It complies with IS: 9103-1999. Superplasticizer is based on a blend of specially selected organic polymers. It is instantly dispersible in water.

**Dosage:** The optimum percentage is best determined by laboratory trials with the mortar mix which enables to study the effects of workability and strength. Laboratory trials with superplasticizers should always be compared with the mix containing no admixture. The optimum dosage was taken as 0.75 litres/100 Kg of cement. The various properties of superplasticizers are presented in Table 4.11.

**Table 4.11 Properties of Superplasticizer**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Property</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Form or state</td>
<td>Liquid</td>
</tr>
<tr>
<td>2</td>
<td>Colour</td>
<td>Brown</td>
</tr>
<tr>
<td>3</td>
<td>Specific gravity</td>
<td>1.22 to 1.225 at 30°C</td>
</tr>
<tr>
<td>4</td>
<td>Chloride content</td>
<td>Nil</td>
</tr>
<tr>
<td>5</td>
<td>Air entrainment</td>
<td>Approximately 1% additional air is entrapped</td>
</tr>
<tr>
<td>6</td>
<td>Compatibility</td>
<td>Can be used with all types of cements except high alumina cement</td>
</tr>
<tr>
<td>7</td>
<td>Workability</td>
<td>Can be used to produce flowing concrete that requires no compaction</td>
</tr>
<tr>
<td>8</td>
<td>Cohesion</td>
<td>Cohesion is improved due to dispersion of cement particles thus minimizing segregation and improving surface finish</td>
</tr>
<tr>
<td>9</td>
<td>Compressive strength</td>
<td>Improvement in strength up to 20% depending up on water cement ratio and other mix parameters</td>
</tr>
<tr>
<td>10</td>
<td>Durability</td>
<td>Reduction in w/c ratio enables increase in density and impermeability thus enhancing durability of concrete</td>
</tr>
</tbody>
</table>
4.3 TEST PROGRAMME

The details of the mineral and chemical admixtures used in the experimental work are presented as test programme in Table 4.12. A total of 60 samples of standard mould used in Vicat’s apparatus were cast and tested for initial and final setting times experiments. The same number of samples of standard mould was used in Le-chatelier’s equipment to test for soundness. A total of 480 mortar cubes of 50 cm² cross-sectional area were tested at different ages (3-day, 7-day, 28-day, 90-day and 365-days) for compressive strength. For entire experimental programme altogether 600 samples were cast and tested for each percentage i.e., 5%, 10% and 15% respectively and for rapid chloride permeability test a total of 60 cylindrical samples were cast and tested.

A brief description of the test programme for the complete investigation is presented in the form of a flow chart as shown in Fig. 4.1.

Table 4.12(a) Details of Test Programme for Mechanical Properties

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Constituents</th>
<th>No. of Specimens for Setting Times Test</th>
<th>No. of Specimens for Soundness Test</th>
<th>No. of Specimens for Compression Test</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Y%PSC</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>Y%PSC + X% Fly Ash</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Y%PSC + X% GGBS</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Y%PSC + X% Microsilica</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>Y%PSC + X% Rice Husk Ash</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>PSC +SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Y%PSC + X% Fly Ash + SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>Y%PSC + X% GGBS + SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>Y%PSC + X% Microsilica+ SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>Y%PSC + X% Rice Husk Ash + SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>11</td>
<td>OPC</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>12</td>
<td>Y%OPC + X% Fly Ash</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>13</td>
<td>Y%OPC +X% GGBS</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>Y%OPC +X% Microsilica</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>Y%OPC +X% Rice Husk Ash</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
<td>16</td>
<td>OPC +SP</td>
<td>3</td>
<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
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<td>21</td>
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<td>3</td>
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</tr>
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<td>Y%OPC +X% Microsilica+ SP</td>
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<td>3</td>
<td>3 × 5</td>
<td>21</td>
</tr>
<tr>
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<td>Y%OPC +X% Rice Husk Ash + SP</td>
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<td>3</td>
<td>3 × 5</td>
<td>21</td>
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</table>
### Table 4.12(b) Details of Test Programme for Durability Properties

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Constituents</th>
<th>No. of Specimens for Acid Test</th>
<th>No. of Specimens for Alkaline Test</th>
<th>No. of Specimens for Sulphate Test</th>
<th>No. of Samples for RCP Test</th>
<th>Total</th>
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</thead>
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<tr>
<td>1</td>
<td>PSC</td>
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<td>1</td>
<td>10</td>
</tr>
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<td>3</td>
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<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Y%PSC + X % GGBS</td>
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<td>3</td>
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<td>10</td>
</tr>
<tr>
<td>4</td>
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<td>10</td>
</tr>
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<td>3</td>
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<td>10</td>
</tr>
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<td>1</td>
<td>10</td>
</tr>
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</tr>
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<td>10</td>
</tr>
<tr>
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</tr>
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<td>3</td>
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<td>10</td>
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<tr>
<td>17</td>
<td>Y%OPC + X % Fly Ash + SP</td>
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<tr>
<td>18</td>
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<tr>
<td>20</td>
<td>Y%OPC + X % Rice Husk Ash + SP</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

**Note:**
- PSC = Portland Slag Cement, OPC = Ordinary Portland Cement, FA = Fly Ash, GGBS = Ground Granulated Blast Furnace Slag, MS = Microsilica, SP = Superplasticizer, and
- $X = 5, 10$ and $15$ respectively, $Y = (100 - X)$

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Collection of the Materials

Properties of the Materials

Mix Proportions

**Portland Slag Cement**

PSC + 5%, 10%, 15% replacement of cement with different admixtures with and without Superplasticizer at different ages

Admixtures Used are
- Fly ash
- Ground Granulated Blast Furnace Slag
- Microsilica
- Rice Husk Ash and Superplasticizer

**Ordinary Portland Cement**

OPC + 5%, 10%, 15% replacement of cement with different admixtures with and without Superplasticizer at different ages

Admixtures Used are
- Fly ash
- Ground Granulated Blast Furnace Slag
- Microsilica
- Rice Husk Ash and Superplasticizer

Casting and Curing of the Specimens

Tests on Mortar Cubes/Cylindrical Specimens

**Mechanical Properties**
- Normal Consistency
- Initial and Final Setting Times
- Soundness
- Compressive Strength

**Durability Tests**
- Acid Test
- Alkaline Test
- Sulphate Test
- Rapid Chloride Permeability Test

**Other Tests**
- X-Ray Diffraction Studies
- Scanning Electron Microscopy
- Energy Dispersive Spectroscopy

Fig. 4.1 Flow Chart Representation for the Complete Investigations Done in the Present Work
4.4 EXPERIMENTAL INVESTIGATIONS

4.4.1 TESTS FOR MECHANICAL PROPERTIES

Normal consistency, initial and final setting times are determined by the Vicat's apparatus, which measures the resistance of cement paste of standard consistency to the penetration of a needle under a total load of 300 g. The initial set is an arbitrary time in the setting process, which is attained when the needle is no longer able to pierce the 40 mm deep pat of the cement paste to within about 5 to 7 mm from the bottom. When the final set is reached, the needle makes an immersion on the surface of the paste but does not penetrate the cement paste at all.

Vicat's apparatus conforming to IS 5513:1976 consists of a frame to which a movable rod having an indicator is attached which gives the depth of penetration. The rod weights 300 g and has diameter and length of 10 mm and 50 mm respectively. Vicat’s mould is in the form of a cylinder and it can be split into two halves. Vicat’s apparatus includes three attachments - plunger for determining normal consistency, square needle for initial setting time, and needle with annular collar for final setting time. Detailed experimental procedures adopted in the investigation are given in the following subsections.

4.4.1.1 Normal Consistency

About 400 g of cement was initially mixed with 30 percent mixing of water. The paste was filled in the mould of Vicat’s apparatus and care was taken such that the cement paste was not pressed forcibly in the mould and the surface of the filled paste was smoothened and leveled. A square needle 1mm x 1mm of size is to be attached to the plunger and then lowered gently on to the surface of the cement paste and is released quickly. As plunger pierces the cement paste, reading on scale was recorded. The experiment was performed carefully away from vibrators and the other disturbances. The test procedure was repeated by increasing the percentage of mixing water at 0.5% increment until the needle reaches 5 to 7 mm from the bottom of the mould. When this condition is fulfilled, the amount of water added was taken as the correct percentage of water for normal consistency. The entire test was completed within 3 to 5 minutes. If the time taken to complete the experiments exceeds 5 minutes then the sample was rejected and fresh sample was taken and the operation was
repeated again. Fresh cement was taken for each repetition of the experiment. The plunger was cleaned each time the experiment is done.

4.4.1.2 Initial and Final Setting Times

Cement paste was prepared by mixing cement with 0.85 time appropriate mixing water required to give a paste of standard consistency. The stop watch was started at the instant the mixing water was added to the cement. After half-a-minute, the paste was thoroughly mixed with fingers for one minute. The mould resting on a nonporous plate was filled completely with cement paste and the surface of filled paste was leveled smooth with the top of the mould. The test was conducted at room temperature of 27 ± 2°C at a relative humidity of 60%. The mould with the cement paste was placed in the Vicat’s apparatus and the needle was lowered gently to make contact with the test block and was then quickly released. The needle thus penetrates the test block and the reading on the graduated scale of Vicat’s apparatus was recorded. The procedure was repeated until the needle fails to pierce the block by about 5 to 7 mm measured from the bottom of the mould. The stop button of stop watch was pushed down and the time was recorded which give the initial setting time. The cement paste was considered finally set when upon applying the needle gently to the surface of test block, the needle makes an immersion, but fails to penetrate and the time was noted which gives the final setting time. The needle was cleaned after every repetition and also care was taken such that there could not be any vibrations.

4.4.1.3 Soundness

Le-chatelier’s apparatus is used for the determination of soundness of cement (IS : 5514, 1969). It consists of a small split cylinder of spring brass of 0.5 mm thickness, forming a mould with 30 mm internal diameter and 30 mm high. On either side of the split are attached two indicators are attached with pointed ends AA, the distance from these ends to the centre of the cylinder being 165 mm. The mould was placed on a glass sheet and was filled with cement paste formed by gauging 100 g of cement with 0.78 times the mixing water required to give a paste of standard consistency. The mould was covered with a glass sheet and a small weight was placed on its top. The mould was then submerged in the water at a temperature of 27 ± 2°C. After 24 hours, the mould was taken out and the distance separating the indicators points was measured. The mould was again submerged in water. Using the water
heaters the water was brought to boiling point within 25 to 35 minutes and the specimen was kept for 3 hours at a boiling point. The mould was removed from water and was allowed to cool down to 27°C. The distance between the indicator points was measured again. The difference between the two measurements represents the unsoundness of cement. For each concentration of mixing water, three samples were tested and the mean value was taken as the unsoundness of cement sample.

4.4.1.4 Compressive Strength

Moulds for the cube specimens of 50 cm² face area, are of metal not amendable, and don’t stick to cement mortar. The sides of the mould are sufficient thick, to prevent spreading and wrapping. The moulds are rigidly constructed in such a manner that the removal of the moulded specimen can be easily without damage. The moulds are machined so that when assembled, the dimensions and the internal faces will be as per required specifications.

The height of the mould and the distance between opposite faces shall be 70.60 mm. The angle between the adjacent interior faces and the top and bottom planes of the mould shall be 90°. The interior faces of the moulds are plane surfaces with a permissible variation of 0.15 mm. The base plate is of such dimensions so as to support the mould during the filling without leakage.

While assembling the mould, the joints between the halves of the mould were covered with a thin film of petroleum jelly and a similar coating of petroleum jelly was applied between the contact surfaces of the bottom of the mould and its base plate in order to ensure that no water escapes during vibration. The interior faces of the mould were treated with a thin coating of mould oil.

The assembled mould was placed on the table of the vibration machine and firmly held in it position by means of a suitable clamp. A hopper of suitable size and shape was attached securely at the top of the mould to facilitate filling and this hopper was not removed until the completion of the vibration period. A mixture of cement and standard sand in the proportion 1:3 by weight was mixed dry (IS 4031(Part 6):1988). Mixing was carried out using a mechanical mixer corresponding to IS specifications. The constituents were first poured into the mixer and mixed in dry condition till uniform color was obtained. Then distilled water spiked to required concentration was
added to it and mixing was continued till a uniform and a homogeneous paste was obtained. Mix the cement and sand in dry condition with a trowel for 1 minute and then add water. The quantity of water shall be \((p/4+3)\%\) of combined weight of cement and sand where, \(p\) is the \% of water required to produce a paste of standard consistency determined earlier. Add water and mix it until the mixture is of uniform colour. The time of mixing shall not be < 3 minutes and not > 4 minutes. Immediately after mixing the mortar, place the mortar in the cube mould and prod with the help of the rod. The mortar shall be prodded 20 times in about 8 sec to ensure elimination of entrained air. If vibrator is used, the period of vibration shall be 2 minutes at the specified speed of 12000±400 vibrations /minutes. Then place the cube moulds in temperature of 27±2°C and 90% relative humidity for 24 hours. After 24 hours remove the cubes from the mould and immediately submerge in clean water till testing. Take out the cubes from water just before testing. Testing should be done on their sides without any packing. 10 liters capacity tin boxes were used for curing cubes in the corresponding water. The rate of loading should be 350 kg/cm²/minute and uniform. Test should be conducted for 3 cubes and the average value is reported as the test result (Kaushik et al., 1988 and Krishnamurthy, 1991).

Three cubes were tested for compressive strength each time in the 40-tonne Universal Testing Machine (UTM) at 3-day, 7-day, 28-day, 90-day and 365-day periods. The cubes were tested on their sides without any packing between the cube and the steel plate of the testing machine. One of the platens is carried on a base and is self-adjusting and the load was steadily and uniformly applied, starting from zero at the rate of 350 kg/cm²/min.

During summer, when the temperature was high, the temperature and humidity were controlled by conducting the experiments in an air-conditioned room. Some experiments were conducted during the night time to maintain the controlled conditions. The temperature and humidity were checked in the room by using thermometer and hygrometer respectively. Since normal consistency, initial and final setting times, soundness and compressive strength of cement are sensitive to temperature and humidity, more or less 27°C temperature and 60% humidity were maintained throughout the experimental work.
4.4.2 TESTS FOR DURABILITY PROPERTIES

4.4.2.1 Acid Attack Test

The mortar cube specimens (of various samples) of size 70.6 mm were casted and after 28 days of water curing, the specimens were removed from the curing tank and allowed to dry for one day. The weights of mortar cube specimen were taken. The acid attack test on specimens was conducted by immersing the cubes in the acid water for 60 days after 28 days of curing. Hydrochloric acid (HCl) with \( \rho \) of about 2 at 5% by weight of water was added to water in which mortar cubes were stored. The \( \rho \) was maintained throughout the period of 60 days. After 60 days of immersion, the mortar cubes were taken out of the acid water and the weights of cubes were recorded after wiping out the acid water on the surface of the cubes. Then, the specimens were tested for compressive strength duly following the procedure prescribed in IS 516:1959. The resistance of mortar cubes to acid attack was found by the loss of weight of specimens and the loss/variation of the compressive strengths on immersion of mortar cubes in acid water. The acid resistance / deterioration of mortar cubes by acid attack is analyzed and discussed in Chapter 5.0.

4.4.2.2 Alkaline Attack Test

To determine the resistance of various mortar mixtures to alkaline attack, the residual compressive strength of mortar cubes size immersed in alkaline waters having 5% of sodium hydroxide (NaOH) by weight of water. The mortar cubes of size 70.6 mm size which were cured in water for 28 days were taken from the curing tanks and allowed to dry for one day. The weights of dry specimens were noted. Then the cubes were immersed in alkaline waters continuously for 60 days. The alkalinity of water was maintained same throughout the test period. After 60 days of immersion in alkaline water, the cubes were removed and the weights of cubes were taken after wiping out the water and grit from the surface of the specimens. The percentage loss in weight was calculated. The compressive strength of cubes which were cured in water for 60 days was determined as per the procedure prescribed in IS 516:1959. The alkaline resistance of various mortar cubes is analyzed and discussed in Chapter 5.0.
4.4.2.3 Sulphate Attack Test

The resistance of mortar cubes to sulphate attack was studied by determining the loss of weight or loss or variation in compressive strength of mortar cubes immersed in sulphate water having 5% of sodium sulphate (Na$_2$SO$_4$) and 5% of magnesium sulphate (MgSO$_4$) by weight of water. The mortar cubes of 70.6 mm size after 28 days of water curing and dried for one day were immersed in 5% Na$_2$SO$_4$ and 5% MgSO$_4$ added water for 60 days. The concentration of sulphate water was maintained throughout the period. After 60 days immersion period, the mortar cubes were removed from the sulphate waters and after wiping out the water and dirt from the surface of cubes and weights of the cubes were taken and percentage loss in weight was calculated and then tested for compressive strength following procedure prescribed in IS 516:1959. The analysis and resistance of various mortar cubes to sulphate attack is discussed in chapter 5.0.

4.4.2.4 Rapid Chloride Permeability Test

The rapid chloride permeability test for different mortar mixtures was carried out as per ASTM C1202-1997. This test method covers the determination of the electrical conductance of mortar to provide a rapid indication of its resistance to penetration of chloride ions.

Standard cylindrical disc specimens of size 100 mm diameter and 50 mm thick after 60 days curing were used in the test. As per ASTMC 1202-1997, specimens with other dimensions, when used for testing, the test result value of the total charge passed through must be adjusted.

The apparatus consists of variable D.C. power supply which feeds constant stabilizer voltage to the cells. The cells are made of polymethyl methacrylate. The mortar specimens are kept in between the cells. The cells are connected to main instrument through 3 pin plug and socket for voltage feeding. The charge of current flowing through the specimen is measured by using an accurate digital current meter. The cells have grooved recess on one face and closed at the other end. The specimen can be fit into the open faces of the cells. One of the cells is filled with 2.4M sodium chloride (NaCl) solution (NaCl-2.4M concentration) and the other is filled with 0.3M sodium hydroxide (NaOH -0.3M) solution.
The cylindrical disc specimens are coated with quick setting epoxy on their curved faces and mounted in the open spaces of the two cells as shown in Figure 4.2. After checking the leak proofness, a 60V potential difference is applied between the electrodes. The electro chemical cell in the assembly results in the migration of chloride ions from sodium chloride solution to sodium hydroxide solution through the pores of the concrete specimen. The current passed was noted at every 30 minutes over a period of 6 hours and the total electric charge passed through the specimen is calculated using the following expression, which gives the total charge passed ($Q_e$) in coulombs.

$$Q_e = 900[I_0 + 2(I_{30} + I_{60} + I_{120} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330} + I_{360})]$$

where $I_0$ = Current at the end of 0 minutes, $I_{30}$ = Current at the end of 30 minutes

$I_{60}$ = Current at the end of 60 minutes, $I_{90}$ = Current at the end of 90 minutes

$I_{120}$ = Current at the end of 120 minutes, $I_{150}$ = Current at the end of 150 minutes

$I_{180}$ = Current at the end of 180 minutes, $I_{210}$ = Current at the end of 210 minutes

$I_{240}$ = Current at the end of 240 minutes, $I_{270}$ = Current at the end of 270 minutes

$I_{300}$ = Current at the end of 300 minutes, $I_{330}$ = Current at the end of 330 minutes

and $I_{360}$ = Current at the end of 360 minutes

As per ASTM C -1202 (5), the mortar resistance to chloride permeability is classified as and is shown in Table 4.13.

**Table 4.13 Classification of Intensity of Chloride Permeability**

<table>
<thead>
<tr>
<th>Charge (coulombs)</th>
<th>Chloride Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4000</td>
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</tr>
<tr>
<td>2000-4000</td>
<td>Moderate</td>
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<tr>
<td>1000-2000</td>
<td>Low</td>
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<tr>
<td>100-1000</td>
<td>Very Low</td>
</tr>
<tr>
<td>&lt;100</td>
<td>Negligible</td>
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</tbody>
</table>

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4.4.3 X-Ray Diffraction Studies

About 95% of all solid materials can be described as crystalline. When X-rays interact with a crystalline substance (Phase), one gets a diffraction pattern.

Hull (1919) discussed the paper titled, "A New Method of Chemical Analysis". He pointed out that "Every crystalline substance gives a pattern; the same substance always gives the same pattern; and in a mixture of substances each produces its pattern independently of the others."

The X-ray diffraction pattern of a pure substance is, therefore, like a fingerprint of the substance. The powder diffraction method is thus ideally suited for characterization and identification of polycrystalline phases.

Today about 50,000 inorganic and 25,000 organic single component, crystalline phases, diffraction patterns have been collected and stored on magnetic or optical media as standards. The main use of powder diffraction is to identify components in a sample by a search/match procedure. Furthermore, the areas under the peak are related to the amount of each phase present in the sample.
An electron in an alternating electromagnetic field will oscillate with the same frequency as the field. When an X-ray beam hits an atom, the electrons around the atom start to oscillate with the same frequency as the incoming beam. In almost all directions we will have destructive interference, that is, the combining waves are out of phase and there is no resultant energy leaving the solid sample. However the atoms in a crystal are arranged in a regular pattern, and in a very few directions we will have constructive interference. The waves will be in phase and there will be well defined X-ray beams leaving the sample at various directions. Hence, a diffracted beam may be described as a beam composed of a large number of scattered rays mutually reinforcing one another.

X-ray diffraction work is normally distinguished between single crystal and polycrystalline or powder applications. The single crystal sample is a perfect (all unit cells aligned in a perfect extended pattern) crystal with a cross section of about 0.3 mm. The single crystal diffractometer and associated computer package is used mainly to elucidate the molecular structure of novel compounds, either natural products or manmade molecules. Powder diffraction is mainly used for “finger print identification” of various solid materials, e.g. asbestos, quartz. In powder or polycrystalline diffraction it is important to have a sample with a smooth plane surface. Normally the sample is grinded down to particles of about 0.002 mm to 0.005 mm cross section. The ideal sample is homogeneous and the crystallites are randomly distributed. The sample is pressed into a sample holder so as to have a smooth flat surface.

In powder diffraction normally the line focus or line source of the tube is utilized. The line source emits radiation in all directions, but in order to enhance the focusing it is necessary to limit the divergences in the direction along the line focus. This is realized by passing the incident beam through a soller slit, which contains a set of closely spaced thin metal plates.

In order to maintain a constant focusing distance it is necessary to keep the sample at an angle THETA (Omega) and the detector at an angle of 2-THETA with respect to the incident beam. A typical diffraction spectrum consists of a plot of reflected intensities versus the detector angle 2-THETA or THETA depending on the
goniometer configuration. The 2-THETA values for the peak depend on the wavelength of the anode material of the X-ray tube.

The basis for the diffraction phenomenon is that the wavelength of the incident radiation (i.e., X-rays) is in the order of magnitude of the interatomic distance in the crystalline solids. Therefore, when an X-ray beam falls on acrystalline material, it will be diffracted by the incidence angle given by Bragg’s law

\[ 2d \sin \theta = n\lambda \]

where \( d \) is the interplanar spacing, \( \lambda \) is the wavelength of the X-ray, \( n \) is an integer and \( \theta \) is the diffraction angle as shown in Fig. 4.3. For different 2\( \theta \) values, the interplanar spacing \( d \) is calculated, the 2\( \theta \) values used are those that give the highest intensities (i.e., peaks) when the sample, in the form of a powder, is scanned.

![Fig. 4.3 Pattern of X-Ray Diffraction](image)

International Center Diffraction Data (ICDD) or formerly known as (JCPDS) Joint Committee on Powder Diffraction Standards is the organization that maintains the database of inorganic and organic spectras. The data base is available from the diffraction equipment manufacturers or from ICDD direct. The details that are obtained are compared with the standard JCPDS data to analyze the results. The XRD Apparatus used in the present study is shown in Fig. 4.4.
4.4.4 Scanning Electron Microscopy

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample-interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques. The SEM is also capable of performing analyses of selected point locations on the sample, this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS), crystalline structure, and crystal orientations (using EBSD).

The SEM has allowed researchers to examine a much bigger variety of specimens as this has many advantages over traditional microscopes. The SEM has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels. Because the SEM uses electromagnets rather than lenses, the
researcher has much more control in the degree of magnification. All of these advantages, as well as the actual strikingly clear images, make the scanning electron microscope one of the most useful instruments in research today.

**Sample Preparation:** Because the SEM utilizes vacuum conditions and uses electrons to form an image, special preparations must be done to the sample. All water must be removed from the samples because the water would vaporize in the vacuum. All metals are conductive and require no preparation before being used. All non-metals need to be made conductive by covering the sample with a thin layer of conductive material. This is done by using a device called a "sputter coater."

The sputter coater uses an electric field and argon gas. The sample is placed in a small chamber that is at a vacuum. Argon gas and an electric field cause an electron to be removed from the argon, making the atoms positively charged. The argon ions then become attracted to a negatively charged gold foil. The argon ions knock gold atoms from the surface of the gold foil. These gold atoms fall and settle onto the surface of the sample producing a thin gold coating. The apparatus used in the present analysis is shown in Fig. 4.5.

![Fig. 4.5 SEM Apparatus in Sri Venkateswara University - Physics Laboratory](image-url)
Process: The SEM is an instrument that produces a largely magnified image by using electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum. The beam travels through electromagnetic fields and lenses, which focus the beam down toward the sample. Once the beam hits the sample, electrons and X-rays are ejected from the sample. Detectors collect these X-rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen. This produces the final image. The process is as shown in the Fig. 4.6.

![Fig. 4.6 Process in SEM Analysis](image)

4.4.5 Energy Dispersive Spectroscopy

Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS) is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on the investigation of an interaction of some source of X-ray excitation and a
sample. It’s characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray spectrum. To stimulate the emission of characteristic X-rays from a specimen, a high-energy beam of charged particles such as electrons or protons or a beam of X-rays, is focused into the sample being studied. At rest, an atom within the sample contains ground state (or unexcited) electrons in discrete energy levels or electron shells bound to the nucleus. The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was. An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray. The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer. As the energy of the X-rays is characteristic of the difference in energy between the two shells, and of the atomic structure of the element from which they were emitted, this allows the elemental composition of the specimen to be measured.

4.5 SUMMING UP

The details of the various materials and the testing procedures used in the present investigation for finding out the mechanical, durability and various morphological properties are presented in this chapter. The results of the tests conducted are explained in detail in the fifth chapter.
CHAPTER V
RESULTS AND DISCUSSIONS

5.1 GENERAL

The results of the present investigation are presented both in tabular and graphical forms. In order to facilitate the analysis, interpretation of the results is carried out at each phase of the experimental work. This interpretation of the results obtained is based on the current knowledge available in the literature as well as on the nature of result obtained. The significance of the result is assessed with reference to the standards specified by the relevant IS codes.

5.2 BASIS FOR INTERPRETATION OF RESULTS

Initial and Final Setting Times

The averages of both the initial and final setting time of three cement samples prepared with different cements replacement by 5%,10% and 15% of fly ash, ground granulated blast furnace slag, microsilica, rice husk ash and also with chemical admixtures of (Conplast SP 430) superplasticizer are compared with ordinary cements. If the difference is less than 30 minutes, the change is considered to be insignificant and if it is more than 30 minutes, the change is considered to be significant. According to IS 8112:1989 the initial setting time should not be less than 30 minutes and final setting time should not be more than 600 minutes.

Soundness Test

The average soundness test results of three samples prepared with different types of cement replaced with mineral and chemical admixtures under consideration are compared with that of the control mix. Comparison shall be made by means of standard cement tests for soundness as specified in IS 269:1976. The IS 269:1976 code specifies that the limit for soundness as per the Le-Chatelier's test result should not be more than 10 mm. The sample made with mineral and chemical admixtures is considered as unsound if the soundness of the specific sample by Le-Chatelier's soundness test is more than 10 mm. The Le-Chatelier's test results of soundness of different types of cements vary proportionately with the concentration of the cement.
Compressive Strength

The average compressive strength of at least three cubes prepared with mineral and chemical admixtures under consideration is compared with that of three cubes prepared with ordinary cements, if the difference in the strength is less than 10%, it is considered to be insignificant and if it is greater than 10%, it is considered to be significant.

Weight Loss

Before conducting the various durability tests for acid, alkaline and sulphate attacks, the mortar cubes are immersed in the respective solutions for 90 days. After taking out from the immersed solutions the weights of the mortar cubes were noted and percentage weight loss was calculated for all the samples. More percentage loss in weight implies that the resistance offered to that particular attack is less.

Durability Tests

The durability tests results for acid, alkaline and sulphate tests regarding compressive strength of three samples prepared with different types of cement replaced with mineral and chemical admixtures are compared with that of three similar ordinary mortar cubes.

After the completion of 90 days immersion in the respective acid, alkaline and sulphate solutions the compressive strengths are determined. From the compressive strength the percentage loss in compressive strengths are determined. More loss in compressive strength means less resistance against that particular attack. More than 10% loss in the strength means a significant loss has occurred.

Cylindrical specimens of both portland slag cement and ordinary portland cement with partial replacement are prepared for testing the penetration of chloride through rapid chloride permeability test (RCPT). The chloride penetrability is calculated and classified according to the specifications presented in Chapter 4 under the description of rapid chloride permeability test as per ASTM C 1202 (presented in Table 4.13).
Special Tests

The micro level structure configuration is studied by generating high resolution images of the various mortar cubes prepared by the replacement of different cement samples with different types of admixtures by using Scanning Electron Microscopy (SEM) and the chemical compounds formed in different combinations of cement mortar are identified by assessing the spatial variations in the chemical compositions which is done by using X-Ray Diffractive studies (XRD) by correlating the results obtained for finding the predominant elements found by using standard Joint Committee on Powder Diffraction Standards (JCPDS) data in Energy Dispersive X-Ray Spectroscopy (EDS).

5.3 RESULTS OF THE EXPERIMENTAL INVESTIGATIONS AND DISCUSSIONS WITH PARTIAL REPLACEMENT OF PORTLAND SLAG CEMENT BY DIFFERENT ADMIXTURES

Fly ash, Ground granulated blast furnace slag, Microsilica and Rice husk ash are the mineral admixtures used and superplasticizer as chemical admixture is used in the present investigation as partial replacement of portland slag cement. The results of various investigations done are discussed in detail in the following sections which are presented in both tabulated and graphical representations.

5.3.1 EFFECT OF FLY ASH ON DIFFERENT PROPERTIES OF PORTLAND SLAG CEMENT

5.3.1.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of cement with 5%, 10% and 15% partial replacement of portland slag cement by fly ash without and with chemical admixture are presented in the Tables 5.1 and the variations of initial setting times, final setting times and compressive strength and percentage change in compressive strength are shown in Fig. 5.1 and Fig. 5.2(a) and Fig. 5.2(b) respectively.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final setting time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive strength (MPa)</th>
<th>Percent change in compressive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>133</td>
<td>217</td>
<td>0.90</td>
<td>22.50</td>
<td>26.20</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5%FA</td>
<td>140</td>
<td>218</td>
<td>1.20</td>
<td>23.29</td>
<td>27.45</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10%FA</td>
<td>145</td>
<td>220</td>
<td>1.10</td>
<td>23.59</td>
<td>27.85</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15%FA</td>
<td>150</td>
<td>233</td>
<td>1.30</td>
<td>23.22</td>
<td>28.13</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>135</td>
<td>235</td>
<td>0.80</td>
<td>22.99</td>
<td>28.84</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5%FA+SP</td>
<td>148</td>
<td>247</td>
<td>1.20</td>
<td>23.42</td>
<td>29.00</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10%FA+SP</td>
<td>165</td>
<td>260</td>
<td>1.10</td>
<td>23.46</td>
<td>29.40</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15%FA+SP</td>
<td>188</td>
<td>278</td>
<td>1.20</td>
<td>24.06</td>
<td>26.90</td>
</tr>
</tbody>
</table>

63
Fig. 5.1 Variation of Initial Setting Time and Final Setting Time with the Partial Replacement of Portland Slag Cement by Fly Ash
Fig. 5.2(a) Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Fly Ash without and with Superplasticizer in Portland Slag Cement
Fig. 5.2(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Fly Ash without and with Superplasticizer in Portland Slag Cement
Initial and Final Setting Times

From the Table 5.1 and Fig. 5.1 it is observed that both the initial and final setting times got retarded by replacement of fly ash in the portland slag cement.

The initial setting times got retarded by 7, 12 and 17 minutes by partial replacement of portland slag cement with 5%, 10% and 15% fly ash respectively without the presence of superplasticizer, which can be treated as insignificant change. When superplasticizer is introduced, there occurred a slight increase in the initial setting times whereas with the partial replacement by fly ash with the presence of superplasticizer the initial setting times have enhanced further more by 13, 32 and 55 minutes respectively for 5%, 10% and 15% replacement of portland slag cement by fly ash and a significant change is identified with 10% and 15% replacement along with the presence of superplasticizer.

A slight increase in the final setting times is observed when portland slag cement is replaced by 5%, 10% and 15% fly ash without the presence of superplasticizer and this change is considered to be insignificant. With the addition of the superplasticizer the final setting time got retarded slightly by an amount of 18 minutes only which is an insignificant change. With the introduction of superplasticizer the final setting times got enhanced in larger amounts by 30, 43 and 61 minutes for 5%, 10% and 15% replacements of fly ash and a significant change is noticed with 10% and 15% replacements.

This significant change observed may be due to the formation of calcium alumina silicate which is presented in the XRD results, which increases the density of the structure by filling the pore spaces with calcium silicate hydrate which is simply called as C-S-H gel also. Ramakrishnan et al. (1981), Lane and Best (1982), Roadway and Fedirko (1989) and Sivasundaram et al. (1990) also reported similar type of results which also shows, an increasing trend in setting times with the addition of fly ash.

Soundness Test Results

Soundness test results of the samples made with portland slag cement are presented in the Tables 5.1. But this variation is very meager and less than the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples is observed both in the case of the samples prepared without and with
the combination of superplasticizer i.e., chemical admixture. So, the samples are considered as sound.

**Compressive Strength**

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of fly ash without and with superplasticizer in portland slag cement are presented in Table 5.1 and Fig. 5.2(a) and percentage change in the compressive strengths are also presented in Table 5.1 and Fig. 5.2(b).

From the Table 5.1 and Fig 5.2(a) it is indicated that the compressive strength continued to increase with age, indicating the pozzolanic action of fly ash. At the early ages i.e., 3 day and 7 day only a little amount of increase in the compressive strength is observed in all the mortar cube samples both with and without superplasticizer. As the percentage replacement of fly ash increases along with age a considerable amount of increase in the compressive strength is observed. The results presented in Table 5.1 and Fig. 5.2(b) depicts that a significant change is observed at later ages i.e., after 90 days and 365 days with 10 and 15% replacement by fly ash, whereas the change is significant even from 7 days onwards with the presence of the superplasticizer. This percentage change in the compressive strength changes from insignificant to significant with the addition of superplasticizer and increase in the percentage replacement from 5% to 15%. This increasing trend may be followed up to an optimum dosage of replacement.

Carette and Malhotra (1984) and Mahmud (1986) also reported an increasing strength with partial replacement by fly ash same as the results obtained.

5.3.1.2 Durability Properties

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage loss in weights when compared to the control mix samples are calculated and these results are presented in Table 5.2 and in Fig. 5.3.
Table 5.2 Effect of Fly Ash Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Percentage Loss in Weight after 60 days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>2.40</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% FA</td>
<td>1.98</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% FA</td>
<td>1.88</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% FA</td>
<td>1.80</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>2.25</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% FA +SP</td>
<td>1.95</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% FA +SP</td>
<td>1.90</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% FA +SP</td>
<td>1.80</td>
</tr>
</tbody>
</table>

It is observed from Table 5.2 and Fig. 5.3 that there is reduction in loss of weight at all the various combinations prepared by partial replacement of portland slag cement by fly ash without and with the presence of superplasticizer on various attacks.

The results presented in Table 5.2 and Fig. 5.3 depicts that the percentage loss occurred is more in the case of acid attack, followed by sulphate attack and then followed by alkaline attack.
As shown in the tabulated values the percentage weight loss gradually reduced with the increase in the percentage replacement by fly ash both in the case of mortar samples prepared without and with the addition of the superplasticizer for all the attacks.

The mortar cubes showed a difference of 0.6% in the weights of control mix sample after immersion in acid and sulphate solutions, which in turn reduced to 0.58%, 0.53% and 0.38% respectively with partial replacement of fly ash by 5%, 10% and 15% without superplasticizer. Similarly a difference of 0.57% is observed for the samples prepared in the presence of superplasticizer without the replacement by fly ash, which is followed by 0.35% reduction in weight in all the other samples prepared with the presence of superplasticizer.

A difference of 0.8% is observed between samples after acid and alkaline attacks with the control mix samples. This reduction in weight is continued to 0.68%, 0.68% and 0.52% respectively for the samples without superplasticizer. A reduction in difference of 0.75%, 0.55%, 0.52% and 0.5% is identified in the samples prepared with the presence of superplasticizer.

The effect of fly ash on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.3 and test results of chloride permeability through Rapid Chloride Permeability Test are presented in Table 5.4 for portland slag cement. The variation of the compressive strength values at 90 days are compared with acid, alkaline and sulphate test and are presented in Fig. 5.4.

The compressive strength values after 90 days and to acid, alkaline, sulphate test and the percentage loss in the compressive strengths are presented in the Table 5.3 and Fig. 5.4 According to the tabulated values it can be concluded that more percentage loss means less resistance is offered by the mortar cubes to that particular attack.
Table 5.3 Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Fly Ash without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>% Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>54.80</td>
<td>47.80</td>
<td>49.30</td>
<td>48.50</td>
<td>12.77</td>
<td>10.04</td>
<td>11.49</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5%FA</td>
<td>58.66</td>
<td>51.80</td>
<td>53.00</td>
<td>52.50</td>
<td>11.69</td>
<td>09.65</td>
<td>10.50</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10%FA</td>
<td>59.24</td>
<td>52.80</td>
<td>54.20</td>
<td>53.60</td>
<td>10.87</td>
<td>08.51</td>
<td>09.52</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15%FA</td>
<td>60.44</td>
<td>54.68</td>
<td>55.80</td>
<td>55.00</td>
<td>09.53</td>
<td>07.68</td>
<td>09.00</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>56.95</td>
<td>50.50</td>
<td>51.70</td>
<td>51.00</td>
<td>11.32</td>
<td>09.22</td>
<td>10.45</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5%FA+SP</td>
<td>61.84</td>
<td>55.40</td>
<td>56.42</td>
<td>55.95</td>
<td>10.41</td>
<td>08.76</td>
<td>09.52</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10%FA+SP</td>
<td>62.54</td>
<td>56.40</td>
<td>57.60</td>
<td>56.92</td>
<td>09.82</td>
<td>07.89</td>
<td>08.98</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15%FA+SP</td>
<td>62.88</td>
<td>57.81</td>
<td>58.73</td>
<td>57.94</td>
<td>08.06</td>
<td>06.60</td>
<td>07.85</td>
</tr>
</tbody>
</table>
Fig. 5.4 Comparison of Compressive Strength with Portland Slag Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Fly Ash
Table 5.4  Permeability of Chloride in Portland Slag Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Fly Ash

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Cement+ Admixture</th>
<th>I₀</th>
<th>I₃₀</th>
<th>I₆₀</th>
<th>I₉₀</th>
<th>I₁₂₀</th>
<th>I₁₅₀</th>
<th>I₁₈₀</th>
<th>I₂₁₀</th>
<th>I₂₄₀</th>
<th>I₂₇₀</th>
<th>I₃₀₀</th>
<th>I₃₃₀</th>
<th>I₃₆₀</th>
<th>I_CUMULATIVE in mA</th>
<th>I_AVERAGE in Coulombs</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>14</td>
<td>14</td>
<td>17</td>
<td>17</td>
<td>2.76</td>
<td>2484</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% FA</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>16</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>3.07</td>
<td>2763</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% FA</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td>1.99</td>
<td>1791</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% FA</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>14</td>
<td>1.74</td>
<td>1566</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
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<td>5</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>1.39</td>
<td>1251</td>
<td>LOW</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% FA+SP</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
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<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>1.41</td>
<td>1269</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% FA+SP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>1.17</td>
<td>1053</td>
<td>LOW</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% FA+SP</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>1.32</td>
<td>1188</td>
<td>LOW</td>
<td></td>
</tr>
</tbody>
</table>
A significant amount of percentage loss in the compressive strengths was identified for the samples prepared with portland slag cement from the values present in Table 5.3. In the case of samples prepared by partial replacement by fly ash these percentage losses in the compressive strength followed a trend of acid attack greater than sulphate attack followed by alkaline attack, which reveal that the mortar cubes are offering more resistance to alkaline attack than sulphate attack than acid attack when exposed to the environment. From the tabulated values it can be noticed that the resistance offered to various attacks is increasing with the increase in the dosage replacement by fly ash and the samples prepared with the addition of the superplasticizer are showing better resistance than samples not having superplasticizer.

With the increase in the dosage of fly ash replacement, the percentage weight loss is reducing and compressive strength started increasing in all the samples tested for durability conditions of acid, alkaline and sulphate attacks, which implies that the resistance offered by the mortar cubes to these attacks is increasing with the partial replacement of portland slag cement by fly ash both without and with superplasticizer presence.

Based on the rapid chloride permeability test results which are shown in Table 5.4 it can be clearly observed that mortar cubes prepared with portland slag cement and portland slag cement with 5% fly ash replacement showed moderate chloride permeability whereas the other combinations showed low permeability to chloride ions which inturn implies that more resistance is offered to chloride penetrability with the increase in the dosage of partial replacement by fly ash.

The increasing resistance to various attacks may be occurring because of the formation of reaction products with the replacement by fly ash, as they fill the pore spaces and changes may occur in the structure of the mortar cubes.

5.3.1.3 SEM, EDS and XRD Results

Scanning Electron Microscopy is done to investigate the external morphology, chemical composition, and crystalline structure and orientation of materials making up the sample. Energy Dispersive Spectroscopy is an analytical technique used for the elemental analysis or chemical characterization of a sample. The X-ray powder diffraction is used to identify components in a sample by a search/match procedure.
Furthermore, the areas under the peak are related to the amount of each phase present in the sample through JCPDS data.

The results of the SEM along with EDS for portland slag cement and ordinary portland cement with 15% fly ash without and with superplasticizer are presented in Fig. 5.5 to Fig. 5.8. The various elements along with percentage weight and atomic percent are also presented in the same figures.

The XRD results are presented in Fig. 5.9 and Fig. 5.10 respectively for portland slag cement without and with superplasticizer and by fly ash replacement with and with superplasticizer. The various possible compounds formed, 2θ angle, structure, standard JCPDS number are presented in the Table 5.5 respectively for various combinations of portland slag cement.

Results of the SEM and EDS of portland slag cement with and without superplasticizer, with and without partial replacement by fly ash are presented in Fig. 5.5 to Fig. 5.8. The results showed that the major elements found are oxygen followed by calcium, silica, iron and then aluminium and magnesium and some more elements in very very small or negligible quantities. When these results are correlated with standard JCPDS data major compounds formed can be analyzed for different combinations of the various elements present.

The micrograph of portland slag cement is shown in Fig. 5.5 reveals that the cement particles shows particle matrix assemblage with inter connected spaces of regular aggregation assemblage inter connected with each other. The micrograph of portland slag cement with superplasticizer reveals that the cement mortar particles are aggregated arrangement with regular interconnected of weaving bunches due to formation of cementitious properties of above particles which is as shown in Fig. 5.7.

The micrograph shown in Fig. 5.6 illustrates that partial replacement of portland slag cement with fly ash showscement mortar particles are aggregation assemblages with intervening bunches due to flocculation of cement mortar particle and formation of hydration reaction products and more cementitious properties, where as the micrograph of partial replacement of portland slag cement by fly ash along with superplasticizer reveals that cement mortar particles are aggregated arrangements with regular aggregation connectors with intra assemblage due to formation of hydration reaction products which is as shown in Fig. 5.8.
**Fig. 5.5 Results of SEM and EDS - Portland Slag Cement**

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C K</td>
<td>1.26</td>
<td>2.23</td>
</tr>
<tr>
<td>O K</td>
<td>52.39</td>
<td>69.34</td>
</tr>
<tr>
<td>Na K</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Mg K</td>
<td>1.30</td>
<td>1.13</td>
</tr>
<tr>
<td>Al K</td>
<td>4.56</td>
<td>3.58</td>
</tr>
<tr>
<td>Si K</td>
<td>11.81</td>
<td>8.90</td>
</tr>
<tr>
<td>K K</td>
<td>0.20</td>
<td>0.11</td>
</tr>
<tr>
<td>Ca K</td>
<td>25.79</td>
<td>13.62</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.48</td>
<td>0.21</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Fe K</td>
<td>2.14</td>
<td>0.81</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
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<td></td>
</tr>
<tr>
<td>Element</td>
<td>Weight%</td>
<td>Atomic%</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>C K</td>
<td>14.20</td>
<td>22.02</td>
</tr>
<tr>
<td>O K</td>
<td>52.12</td>
<td>60.66</td>
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<tr>
<td>Na K</td>
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<td>0.06</td>
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<tr>
<td>Mg K</td>
<td>0.40</td>
<td>0.31</td>
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<tr>
<td>Al K</td>
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<td>1.46</td>
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<tr>
<td>Si K</td>
<td>6.26</td>
<td>4.15</td>
</tr>
<tr>
<td>Ca K</td>
<td>23.41</td>
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<tr>
<td>Ti K</td>
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<td>0.01</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.09</td>
<td>0.03</td>
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<tr>
<td>Fe K</td>
<td>1.32</td>
<td>0.44</td>
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<tr>
<td>Totals</td>
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</tr>
</tbody>
</table>

Fig. 5.6 Results of SEM and EDS - Portland Siag Cement + Fly Ash
Fig. 5.7 Results of SEM and EDS - Portland Slag Cement + Superplasticizer
Fig. 5.8 Results of SEM and EDS - Portland Slag Cement + Superplasticizer + Fly Ash

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>44.46</td>
<td>64.68</td>
</tr>
<tr>
<td>Na K</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.44</td>
<td>0.42</td>
</tr>
<tr>
<td>Al K</td>
<td>2.86</td>
<td>2.47</td>
</tr>
<tr>
<td>Si K</td>
<td>9.40</td>
<td>7.79</td>
</tr>
<tr>
<td>Cl K</td>
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<td>0.35</td>
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<td>K K</td>
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<tr>
<td>Ca K</td>
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<tr>
<td>Ti K</td>
<td>0.30</td>
<td>0.15</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Fe K</td>
<td>2.15</td>
<td>0.90</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100.00</strong></td>
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</tr>
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</table>
Fig. 5.9 XRD Results for Control Mixes of Portland Slag Cement
Fig. 5.10 XRD Results for Portland Slag Cement with Partial Replacement by Fly Ash
### Table 5.5 XRD Results for Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>2θ Angle (Degrees)</th>
<th>Structure</th>
<th>Wave Length (Å)</th>
<th>Possible Compound</th>
<th>JCPDS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PSC</td>
<td>26.6864</td>
<td>Orthorhombic</td>
<td>1.54060</td>
<td>CaMgSiO$_3$ Calcium Magnesium Silicate (Monticellite)</td>
<td>75-1569</td>
</tr>
<tr>
<td>2.</td>
<td>PSC+FA</td>
<td>26.504</td>
<td>Orthorhombic</td>
<td>1.54056</td>
<td>Al$_2$SiO$_3$ Aluminium Silicate (Mullite)</td>
<td>15-0776</td>
</tr>
<tr>
<td>3.</td>
<td>PSC+GGBS</td>
<td>26.891</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca$_2$Al$_2$SiO$_5$- Calcium Aluminium Silicate (Mullite)</td>
<td>82-0548</td>
</tr>
<tr>
<td>4.</td>
<td>PSC+MS</td>
<td>26.686</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca(SiO$_2$)$_2$ Calcium Silicate</td>
<td>89-6463</td>
</tr>
<tr>
<td>5.</td>
<td>PSC+RHA</td>
<td>26.6864</td>
<td>Anorthic</td>
<td>1.54060</td>
<td>CaO(Al$_2$O$_3$)$_2$ Calcium Hydroxide (Hematite)</td>
<td>89-8575</td>
</tr>
<tr>
<td>6.</td>
<td>PSC+SP</td>
<td>26.686</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca(Al$_2$O$_3$)$_2$ Calcium Aluminium Oxide</td>
<td>89-3851</td>
</tr>
<tr>
<td>7.</td>
<td>PSC+FA+SP</td>
<td>26.504</td>
<td>Orthorhombic</td>
<td>1.5405</td>
<td>CaAl$_2$Si$_2$O$_6$ Calcium Aluminium Silicate</td>
<td>05-0528</td>
</tr>
<tr>
<td>8.</td>
<td>PSC+GGBS+SP</td>
<td>26.504</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>CaO(Al$_2$O$_3$)$_2$ Calcium Aluminium Oxide (Mullite)</td>
<td>80-2107</td>
</tr>
<tr>
<td>9.</td>
<td>PSC+MS+SP</td>
<td>26.686</td>
<td>Orthorhombic</td>
<td>1.54060</td>
<td>Ca(SO$_4$)$_2$ Calcium Sulphate</td>
<td>19-1232</td>
</tr>
<tr>
<td>10.</td>
<td>PSC+RHA+SP</td>
<td>26.6864</td>
<td>Orthorhombic</td>
<td>1.54056</td>
<td>Al$_6$Si$_2$O$_13$ Aluminium Silicate (Mullite)</td>
<td>15-0776</td>
</tr>
</tbody>
</table>
The possible compounds formed in the various combinations of portland slag cement, portland slag cement with fly ash, portland slag cement with superplasticizer and portland slag cement with fly ash and superplasticizer are calcium magnesium silicate (Monticellite), aluminium silicate (Mullite), calcium aluminium oxide and calcium aluminium silicate respectively. Orthorhombic structure is maintained most of the times even with the partial replacement by fly ash and addition of superplasticizer along with fly ash.

It is clearly observed from the figures that with the increase in the dosage of fly ash, a dense microstructure is formed which is helpful in increasing most of the properties of cement as recently presented by Shafiq et al. (2012).

A delay in the setting times, increase in the compressive strengths, decreasing in the percentage weight loss and increase in the resistance to various attacks is occurring because of the formation of hydration products and reaction compounds such as monticellite, mullite, calcium aluminium oxide and calcium aluminium silicate with the replacement by fly ash.

5.3.2 EFFECT OF GROUND GRANULATED BLAST FURNACE SLAG ON DIFFERENT PROPERTIES OF PORTLAND SLAG CEMENT

5.3.2.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of the samples with 5%, 10% and 15% partial replacement of portland slag cement by ground granulated blast furnace slag with and without superplasticizer are presented in the Table 5.6 and the variations in the setting times and compressive strengths and percentage change in compressive strength of various combinations of portland slag cement with ground granulated blast furnace slag cement are shown in Fig. 5.11 and Fig. 5.12(a) and Fig. 5.12(b) respectively.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>133</td>
<td>217</td>
<td>0.90</td>
<td>22.50 26.20 36.40 54.80 69.00</td>
<td>0 0 0 0 0</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% GGBS</td>
<td>136</td>
<td>230</td>
<td>0.60</td>
<td>21.45 27.69 38.07 59.09 74.18</td>
<td>4.67 5.70 4.60 7.83 7.95</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% GGBS</td>
<td>140</td>
<td>232</td>
<td>1.10</td>
<td>22.02 27.04 38.28 61.27 78.00</td>
<td>2.14 3.24 5.17 11.81 13.04</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% GGBS</td>
<td>150</td>
<td>240</td>
<td>1.00</td>
<td>22.78 27.42 39.60 63.40 80.00</td>
<td>1.25 4.69 8.78 15.69 15.94</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>135</td>
<td>235</td>
<td>0.67</td>
<td>22.99 28.84 38.85 56.95 72.18</td>
<td>2.18 10.07 6.73 3.92 4.60</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% GGBS+SP</td>
<td>155</td>
<td>248</td>
<td>1.13</td>
<td>24.46 31.18 38.92 60.75 76.86</td>
<td>8.02 15.98 6.92 10.86 11.39</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% GGBS+SP</td>
<td>160</td>
<td>256</td>
<td>1.00</td>
<td>24.59 31.14 41.06 62.42 78.97</td>
<td>9.28 18.86 12.80 13.91 14.45</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% GGBS+SP</td>
<td>165</td>
<td>266</td>
<td>1.05</td>
<td>24.14 31.24 42.25 64.99 82.50</td>
<td>7.29 19.33 16.08 18.59 19.56</td>
</tr>
</tbody>
</table>
Fig. 5.11 Variation of Initial and Final Setting Times with Partial Replacement of Portland Slag Cement by GGBS
Fig. 5.12(a) Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Portland Slag Cement
Fig. 5.12(b)  Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Portland Slag Cement
**Initial and Final Setting Times:**

From the Table 5.6 it is observed that both the initial final setting times got retarded by partial replacement of ground granulated blast furnace slag in the portland slag cement.

The initial setting times are 136, 140, 150 minutes respectively with 5%, 10% and 15% replacement of portland slag cement without the presence of superplasticizer which show an increase of 03, 07 and 17 minutes respectively. The change in these initial setting times is considered as insignificant as these values are slightly more than that of the portland slag cement. Similarly an increase in the final setting times is also observed which are 13, 15 and 23 minutes more than that of the portland slag cement combinations respectively and these changes are also considered as insignificant.

The initial setting time for the sample prepared by the addition of superplasticizer to the portland slag cement showed a delay of only 2 minutes which is very meager when compared to the initial setting time of portland slag cement. The initial setting times for the various other samples prepared by partial replacement of cement by ground granulated blast furnace slag along with superplasticizer are 155, 160 and 165 minutes respectively and an increase of 22, 27 and 32 minutes is observed. The change in setting times of the samples prepared by 5%, and 10% replacement of GGBS along with superplasticizer is considered as insignificant, where as the change in the case of 15% is significant. Similarly final setting times also retarded by an amount of 18, 31, 39 and 49 minutes respectively. Here except the sample prepared with the addition of superplasticizer with portland slag cement, all the other combinations the change is considered as significant as they are exceeding a change of 30 minutes. As rightly said by the investigators Wainwright and Ait-Aider in the year 1995 here also it can be concluded that setting times of cement were increased with the increase in the GGBS content. But, the change is slightly more in the presence of superplasticizer than the mortar cubes prepared by GGBS replacement without superplasticizer.

The retardation that has occurred may be due to the addition of GGBS to portland slag cement which occupies the pore spaces and reacts with the various ingredients present in the portland slag cement and results in the formation of various reaction compounds along with C-S-H gel which brings the changes in the properties and also the structure.
Soundness Test Results

Soundness test results of the samples made with partial replacement of portland slag cement by GGBS are presented in the Tables 5.6. and the difference between these values with that of portland slag cement ranges between 0.23 mm to 0.30 mm which are negligibly smaller than that of the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples is noticed both in the case of the samples prepared without and with the combination of superplasticizer.

Compressive Strength Values

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of GGBS without and with superplasticizer in portland slag cement along with the percentage change in the compressive strength are presented in Table 5.6 and the graphical representations are presented in Fig. 5.12(a) and Fig. 5.12(b) respectively.

From the Table 5.6 and Fig 5.12(a) it can be clearly pragmatic that the compressive strength continued to increase as the age prolongs, indicating the pozzolanic action of GGBS. At the early ages i.e., 3 days the compressive strengths developed more slowly than the control mix, after which the rate of strength development increased sharply and are greater than that of control mix sample prepared without superplasticizer. These variations are noticed to be similar to the results reported by Hogan and Meusel.

The results of percentage change in the compressive strengths presented in Table 5.6 and Fig. 5.12(b) showed less gain in the strength up to 28 days and afterwards the gain in the strength is considered to be significant. As the percentage replacement of GGBS increases along with superplasticizer, at all ages a considerable amount of increase in the compressive strengths are clearly observed. Similar conclusions were drawn by Barnett et al. (2006) by investigating the strength development of mortar cubes containing GGBS and all mortars gained strength.

5.3.2.2 Durability Properties

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the
percentage weight loss when compared to the control mix samples are calculated. The effect of weight loss describes the resistance offered to various attacks by the increase in the dosage replacement of portland slag cement by ground granulated blast furnace slag. The effect of ground granulated blast furnace slag replacement on portland slag cement without and with superplasticizer on percentage weight loss are presented in Table 5.7 and the graphical representation is shown in Fig. 5.13.

Table 5.7 Effect of Ground Granulated Blast Furnace Slag Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>Acid Solution</th>
<th>Alkaline Solution</th>
<th>Sulphate Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% PSC</td>
<td>2.40</td>
<td>1.60</td>
<td>1.80</td>
</tr>
<tr>
<td>2</td>
<td>95% PSC + 5% GGBS</td>
<td>2.26</td>
<td>1.55</td>
<td>1.60</td>
</tr>
<tr>
<td>3</td>
<td>90% PSC + 10% GGBS</td>
<td>2.15</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>4</td>
<td>85% PSC + 15% GGBS</td>
<td>2.02</td>
<td>1.30</td>
<td>1.20</td>
</tr>
<tr>
<td>5</td>
<td>100% PSC + SP</td>
<td>2.25</td>
<td>1.50</td>
<td>1.68</td>
</tr>
<tr>
<td>6</td>
<td>95% PSC + 5% GGBS + SP</td>
<td>1.95</td>
<td>1.39</td>
<td>1.58</td>
</tr>
<tr>
<td>7</td>
<td>90% PSC + 10% GGBS + SP</td>
<td>1.86</td>
<td>1.30</td>
<td>1.48</td>
</tr>
<tr>
<td>8</td>
<td>85% PSC + 15% GGBS + SP</td>
<td>1.76</td>
<td>1.20</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Various Combinations of Portland Slag Cement with Ground Granulated Blast Furnace Slag

Fig. 5.13 Effect of Ground Granulated Blast Furnace Slag Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss
The results presented in Table 5.7 and Fig. 5.13 depicts that the percentage loss in weight started declining with the increase in dosage replacement of portland slag cement by ground granulated blast furnace slag in all the samples tested for acid, alkaline and sulphate attacks which also reveals that more amount of percentage weight loss has occurred due to acid attack followed by sulphate and then by alkaline attack.

The difference in the percentage weight loss has changed from 0.14% to 0.38% in the case of mortar cubes prepared with partial replacement by GGBS without the presence of superplasticizer for acid attack. In the similar mode the difference has changed from 0.15% to 0.64% with the presence of superplasticizer when compared to mortar cubes prepared by only portland slag cement which is considered as control mortar cubes. A difference in the percentage weight loss of 0.05% to 0.3% and 0.1% to 0.4% has appeared in the mortar cubes tested for alkaline attack by partial replacement by GGBS without and with the presence of the superplasticizer respectively. For sulphate attack the difference observed is changing from 0.2% to 0.6% and 0.12% to 0.6% in the mortar cubes prepared by partial replacement of portland slag cement without and with the presence of superplasticizer respectively.

All the results shows that mortar cubes with superplasticizer presence are showing more resistance than cubes without superplasticizer. The results of the percentage weight loss implies that the percentage weight loss is more in acid attack than sulphate than alkaline attacks which reveals that the mortar cubes prepared by various combinations of GGBS show more resistance to alkaline followed by sulphate and then by acid attacks. This may be because of the formation of pozzolanic reaction product such as C-S-H gel as one of the reaction products which fills the pore spaces along with the formation of calcium aluminium silicate and calcium aluminium oxide which are presented in SEM micrographs and XRD results also. This analysis is same as that of Daube and Bakker (1986), who have concluded that the addition of GGBS modifies the products and the pore structure.

The effect of GGBS on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.8 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.9 for portland slag cement. The variation of the compressive strength values at 90 days are compared with acid, alkaline and sulphate test and are presented in Fig. 5.14. As already discussed more percentage loss means less resistance is offered by the mortar cubes to that particular attack.
Table 5.8  Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement by Ground Granulated Blast Furnace Slag without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 days) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>54.80</td>
<td>47.80</td>
<td>49.30</td>
<td>48.50</td>
<td>12.77</td>
<td>10.04</td>
<td>11.49</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% GGBS</td>
<td>59.09</td>
<td>52.60</td>
<td>53.50</td>
<td>52.80</td>
<td>11.99</td>
<td>09.46</td>
<td>10.64</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% GGBS</td>
<td>61.27</td>
<td>54.65</td>
<td>56.10</td>
<td>55.50</td>
<td>10.80</td>
<td>08.43</td>
<td>09.42</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% GGBS</td>
<td>63.40</td>
<td>57.60</td>
<td>58.85</td>
<td>59.00</td>
<td>09.15</td>
<td>07.18</td>
<td>08.52</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>56.95</td>
<td>50.50</td>
<td>51.70</td>
<td>51.00</td>
<td>11.32</td>
<td>09.22</td>
<td>10.45</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% GGBS+SP</td>
<td>60.75</td>
<td>54.30</td>
<td>55.40</td>
<td>54.90</td>
<td>10.62</td>
<td>08.81</td>
<td>09.63</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% GGBS+SP</td>
<td>62.42</td>
<td>56.50</td>
<td>58.00</td>
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<td>09.48</td>
<td>07.08</td>
<td>08.52</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% GGBS+SP</td>
<td>64.99</td>
<td>59.98</td>
<td>61.00</td>
<td>60.00</td>
<td>07.71</td>
<td>06.14</td>
<td>07.68</td>
</tr>
</tbody>
</table>
Different Doses of Ground Granulated Blast Furnace Slag

Compressive Strength (MPa)

- 100% PSC
- 95% PSC + 5% GGBS
- 90% PSC + 10% GGBS
- 85% PSC + 15% GGBS
- 5% PSC + 15% SP
- 0.5% SP
- 90% SP
- 90% SP + 10% GGBS
- 90% SP + 15% GGBS
- 90% SP + 20% GGBS

Comparison of Compressive Strength with Portland Slag Cement at 90 Days to Acid, Alkaline and Sulphate Tests with

Various Combinations of PSC with Ground Granulated Blast Furnace Slag
Table 5.9 Permeability of Chloride in Portland Slag Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Ground Granulated Blast Furnace Slag

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement+ Admixture</th>
<th>I₀</th>
<th>I₃₀</th>
<th>I₆₀</th>
<th>I₉₀</th>
<th>I₁₂₀</th>
<th>I₁₅₀</th>
<th>I₁₈₀</th>
<th>I₂₁₀</th>
<th>I₂₄₀</th>
<th>I₂₇₀</th>
<th>I₃₀₀</th>
<th>I₃₃₀</th>
<th>I₃₆₀</th>
<th>I₄₅₅</th>
<th>I₄₈₅</th>
<th>I₅₁₅</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
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<td>14</td>
<td>14</td>
<td>17</td>
<td>17</td>
<td>2.76</td>
<td>2484</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% GGBS</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>17</td>
<td>2.36</td>
<td>2124</td>
<td>MODERATE</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% GGBS</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td></td>
<td>1.48</td>
<td>1332</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% GGBS</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td></td>
<td></td>
<td>1.08</td>
<td>972</td>
<td>VERY LOW</td>
<td></td>
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<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>9</td>
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<td>10</td>
<td>11</td>
<td>1.39</td>
<td>1251</td>
<td>LOW</td>
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</tr>
<tr>
<td>6</td>
<td>95%PSC +5% GGBS +SP</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
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<td>12</td>
<td>14</td>
<td>1.50</td>
<td>1350</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% GGBS +SP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>11</td>
<td></td>
<td>0.86</td>
<td>774</td>
<td>VERY LOW</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% GGBS +SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>0.14</td>
<td>126</td>
<td>VERY LOW</td>
<td></td>
</tr>
</tbody>
</table>

94
Based on the experimental investigations presented in the Table 5.8 the mortar cubes prepared by portland slag cement showed a percentage loss in compressive strength of 12.77, 10.04 and 11.49 for acid, alkaline and sulphate resistance attack tests respectively, which indicates that the mortar cubes showed greater resistance to alkaline than sulphate than acid attacks when they are exposed to environment.

The mortar cubes prepared by remaining all other combinations of portland slag cement by 5%, 10% and 15% GGBS replacement with and without superplasticizer and portland slag cement with superplasticizer also showed resistance of the same order. But the resistance offered by the mortar cubes prepared by the addition of the superplasticizer is more than that of the cubes without superplasticizer. The results depicts that with the partial replacement of portland slag cement by GGBS showed an improvement in the resistance to various attacks like acid, alkaline and sulphate. These results disclose that increasing the GGBS contents in portland slag cement mortars increased the sulphate resistance also substantially which is as suggested by Fearson (1986).

The rapid chloride permeability test results presented in Table 5.9 depicts that the control mix mortar cylinder sample prepared by portland slag cement and portland slag cement with 5% replacement by GGBS shows moderate resistance to chloride permeability, whereas the mortar cubes prepared by 10% replacement by GGBS, portland slag cement with superplasticizer and 5% replacement with the presence of superplasticizer showed low permeability of chloride ions as the charge passed through the mortar cubes is less. Finally the mortar cube samples prepared by 15% replacement with and without superplasticizer and 10% and 15% replacement by GGBS with superplasticizer showed very low penetration of chloride ions which implies that greater resistance is offered by the samples against chloride attack with the increase in the dosage of GGBS which is also concluded from their investigations by Cheng et al. (2005).

5.3.2.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for portlandslag cement with 15% replacement by GGBS without and with superplasticizer are presented in Fig. 5.15 and Fig. 5.16 respectively. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of Portland slag cement with partial replacement by GGBS without and with superplasticizer are presented in Fig. 5.17.
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>51.32</td>
<td>68.77</td>
</tr>
<tr>
<td>Si K</td>
<td>22.72</td>
<td>17.35</td>
</tr>
<tr>
<td>Ca K</td>
<td>25.96</td>
<td>13.88</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>100.00</td>
</tr>
</tbody>
</table>

Fig. 5.15 Results of SEM and EDS - Portland Slag Cement + Ground Granulated Blast Furnace Slag
Fig. 5.16 Results of SEM and EDS - Portland Slag Cement + GGBS+ Superplasticizer
Fig. 5.17  XRD Results for Portland Slag Cement with Partial Replacement by Ground Granulated Blast Furnace Slag
The micrograph of partial replacement of portland slag cement with ground granulated blast furnace slag without superplasticizer implies that the cement mortar particles are regular aggregations with inter connected particle assemblage due to flocculation, which fills the pore spaces by reaction products such as C-S-H gel and results in a hardened cementitious material, whereas the micrograph with partial replacement by GGBS with superplasticizer indicates particle matrix assemblage with inter connected bunches of edge to edge formation which are connected with each other.

The major amounts of elements present in both the combinations are oxygen, silica and calcium. By considering these elements, the major compounds formed are identified by matching 2θ angle with standard JCPDS data which are calcium aluminium silicate and calcium aluminium oxide respectively and both of them exhibit monoclinic structure. The peaks formed are around 26° which can be seen in the XRD results presented in Fig. 5.17 and Table 5.5.

Finally an increase in the both the initial and final setting time is observed with the increase in the percentage replacement by GGBS both with and without superplasticizer. The compressive strengths of cements developed slowly than the controls for the first 3 days, after which the rate of strength development increased sharply and are greater than controls. The percentage loss in weights has reduced with the introduction of GGBS and this reduction shows that an increased resistance is offered by the mortar cubes with the increase in the dosage of GGBS content to acid, alkaline and sulphate attacks. In RCPT results very low penetrability to chloride ions is exhibited which implies that greater resistance is offered to chloride attack also. All these changes occurred because of the formation of inter connected particle assemblage due to flocculation, which fills up the pore spaces by the formation of the C-S-H gel which intensified with available increase indicating more dense structures and large amount of additional C-S-H in the presence of GGBS content and the formation of compounds like calcium aluminium silicate and calcium aluminium oxide.

5.3.3 **EFFECT OF MICROSILICA ON DIFFERENT PROPERTIES OF PORTLAND SLAG CEMENT**

5.3.3.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of cement mortar cubes with 5%, 10%
and 15% partial replacement of portland slag cement by microsilica without and with superplasticizer are presented in the Table 5.10 and the variations in setting times and compressive strengths and percentage change in compressive strengths are exhibited in the graphical representation in Fig. 5.18 and Fig. 19(a) and Fig. 19(b) respectively.

**Initial and Final Setting Times**

From the Table 5.10 and Fig. 5.18 it is observed that the initial setting times got accelerated at the small dosage changes and then retarded by smaller amounts without superplasticizer and got retarded with the addition of superplasticizer whereas final setting times got retarded by partial replacement of microsilica in the portland slag cement samples.

The initial setting times of mortar samples prepared by 5%, 10% replacement of portland slag cement by microsilica without the presence of superplasticizer show a decrease of 3 and 1 minutes respectively and an increase of just 2 minutes occurred with 15% replacement by GGBS. The change in these initial setting times is considered as insignificant as a change of just a few minutes is observed when compared to the portland slag cement samples. Similarly the final setting times are delayed only by 3, 8 and 13 minutes more than that of the portland slag cement samples respectively and these changes are also considered to be insignificant.

An increase of just 2 minutes in the initial setting time for the sample prepared in the presence of superplasticizer with portland slag cement is observed and for the samples prepared by partial replacement of cement by microsilica along with superplasticizer showed delays of 14, 17 and 25 minutes respectively. The changes that occurred in the samples prepared by 5%, 10% and 15% replacement of microsilica along with superplasticizer are considered to be insignificant. Similarly a delay of 18 minutes is noticed in the case of sample prepared by portland slag cement with superplasticizer, where as a delay of 28, 38 and 43 minutes is exhibited by the samples prepared by 5%, 10% and 15% replacement of portland slag cement by microsilica. The changes in the case of 10% and 15% replacement are considered to be significant as they are exceeding 30 minutes.
Table 5.10  Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Microsilica without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>133</td>
<td>217</td>
<td>0.90</td>
<td>22.50</td>
<td>26.20</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% MS</td>
<td>130</td>
<td>220</td>
<td>0.70</td>
<td>21.67</td>
<td>29.21</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% MS</td>
<td>132</td>
<td>225</td>
<td>0.80</td>
<td>23.17</td>
<td>29.73</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% MS</td>
<td>135</td>
<td>230</td>
<td>0.90</td>
<td>22.24</td>
<td>26.38</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>135</td>
<td>235</td>
<td>0.67</td>
<td>22.99</td>
<td>28.84</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% MS+SP</td>
<td>147</td>
<td>245</td>
<td>0.70</td>
<td>24.80</td>
<td>30.16</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% MS+SP</td>
<td>150</td>
<td>255</td>
<td>0.80</td>
<td>24.53</td>
<td>31.15</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% MS+SP</td>
<td>158</td>
<td>260</td>
<td>0.90</td>
<td>23.84</td>
<td>30.62</td>
</tr>
</tbody>
</table>
Fig. 5.18. Variation of Initial and Final Setting Times with Partial Replacement of Portland Slag Cement by Microsilica
Fig. 5.19(a) Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica without and with Superplasticizer in Portland Slag Cement
Fig. 5.19(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica without and with Superplasticizer in Portland Slag Cement
From the setting times results it can be concluded that for smaller percentage replacements, the settings times are not affected much which are same as the conclusions drawn by Lohtia and Joshi (1996) and Rao (2003).

**Soundness Test Results**

Soundness test results of the samples made with partial replacement of portland slag cement by microsilica are presented in the Tables 5.10. and these values ranges between 0.67 mm to 0.39 mm. But these variations are considered as very minute when compared to the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples is observed both in the case of the samples prepared with and without the combination of superplasticizer.

**Compressive Strength Values**

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of microsilica without and with superplasticizer in portland slag cement along with the percentage change in the compressive strengths are reported in Table 5.10 and the graphical representation of the compressive strengths and percentage change in the compressive strength are presented in Fig. 5.19(a) and Fig. 5.19(b) respectively.

From the results presented in Table 5.10 and Fig. 5.19(a) it can be clearly recognized that the compressive strength increases with the increase in microsilica replacement up to 10% both in the case of mortar cubes prepared without and with the presence of superplasticizer and then it started retreating with the further increase in the percentage replacement of microsilica to 15% at all the ages considered, though the increase is slightly appeared at the early ages.

The variation in the percentage change in the compressive strength is presented in Table 5.10 and Fig. 5.19(b). Percentage change in compressive strength varies from 2% to even 20% at some ages showing a wide range of variations. As found by Huang and Feldman (1985) the addition of silica fume to mortar resulted in an improved bond between the hydrated cement matrix and sand in the mix, hence increasing strength with a decrease in the pore spaces resulting in a dense microstructure also which is also identified in SEM analysis. The results of the SEM analysis shows flakey arrangements and XRD results showed the change of mooclinic structure to orthorhombic structure.
5.3.3.2 Durability Properties

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage weight loss when compared to the control mix samples are calculated. The effect of Microsilica on partial replacement of Portland slag cement are presented in Table 5.11 and in Fig. 5.20.

Table 5.11 Effect of Microsilica Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>Acid Solution</th>
<th>Alkaline Solution</th>
<th>Sulphate Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% PSC</td>
<td>2.40</td>
<td>1.60</td>
<td>1.80</td>
</tr>
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<td>2</td>
<td>95% PSC + 5% MS</td>
<td>2.32</td>
<td>1.56</td>
<td>1.60</td>
</tr>
<tr>
<td>3</td>
<td>90% PSC + 10% MS</td>
<td>2.20</td>
<td>1.45</td>
<td>1.55</td>
</tr>
<tr>
<td>4</td>
<td>85% PSC + 15% MS</td>
<td>2.28</td>
<td>1.50</td>
<td>1.62</td>
</tr>
<tr>
<td>5</td>
<td>100% PSC + SP</td>
<td>2.25</td>
<td>1.50</td>
<td>1.68</td>
</tr>
<tr>
<td>6</td>
<td>95% PSC + 5% MS + SP</td>
<td>2.10</td>
<td>1.30</td>
<td>1.45</td>
</tr>
<tr>
<td>7</td>
<td>90% PSC + 10% MS + SP</td>
<td>2.05</td>
<td>1.25</td>
<td>1.40</td>
</tr>
<tr>
<td>8</td>
<td>85% PSC + 15% MS + SP</td>
<td>2.10</td>
<td>1.35</td>
<td>1.39</td>
</tr>
</tbody>
</table>

Fig. 5.20 Effect of Microsilica Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss
The results presented in Table 5.11 and Fig. 5.20 depicts that the percentage loss in weight started declining with the increase in dosage replacement of portland slag cement by microsilica up to 10% and then the percentage weight loss is slightly increased at 15% replacement in the samples tested for acid, alkaline and sulphate attacks which also reveals that more amount of percentage weight loss has occurred due to acid attack followed by sulphate and then by alkaline attack.

A difference in the percentage weight loss of 0.08%, 0.20% and 0.12% is observed in the case of mortar cubes prepared with 5%, 10% and 15% partial replacement by microsilica respectively without the presence of superplasticizer for acid attack. In the similar manner a difference of 0.15%, 0.30%, 0.35% and 0.30% with the presence of superplasticizer and with partial replacement by 5%, 10% and 15% microsilica along with superplasticizer respectively when compared to mortar cubes prepared by only portland slag cement. A difference of 0.04% followed by 0.15% and 0.1% occurred with the presence of superplasticizer, which changed to 0.1%, 0.3%, 0.35% and 0.25% with the addition of superplasticizer to portland slag cement and with partial replacement of by microsilica for alkaline attack. For sulphate attacks in the mortar cubes prepared with partial replacement of microsilica without superplasticizer, a difference in the percentage weight loss of 0.2%, 0.25% and 0.18% is exhibited. With the addition of the superplasticizer a weight loss with a difference of 0.12%, 0.35%, 0.4% and 0.41% occurred when compared to the mortar cubes of portland slag cement.

From the above results it is recognized that weight loss is more in the case of acid test, than sulphate test than alkaline test. So, more resistance is exhibited against alkaline test followed by sulphate test and then finally by acid test. This loss in weight decreased with the addition of microsilica up to 10% replacement and then presented a slight increase in the weight loss by 15% replacement. This further implies that optimum dosage replacement of microsilica is 10% out of 5%, 10% and 15%.

The effect of partial replacement of microsilica on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.12 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.13 for portland slag cement. The variation of the compressive strengths at 90 day are compared with acid, alkaline and sulphate test and are presented in Fig. 5.21 in the form of graphical representation. As already presented in the previous discussions, more percentage loss in compressive strength indicates that less resistance is offered by the mortar cubes to that particular attack.
Table 5.12 Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Microsilica without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 days) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>% Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>54.80</td>
<td>47.80</td>
<td>49.30</td>
<td>48.50</td>
<td>12.77</td>
<td>10.04</td>
<td>11.49</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% MS</td>
<td>59.19</td>
<td>52.50</td>
<td>53.70</td>
<td>52.90</td>
<td>11.30</td>
<td>09.27</td>
<td>10.62</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% MS</td>
<td>60.54</td>
<td>54.90</td>
<td>55.40</td>
<td>54.65</td>
<td>09.32</td>
<td>08.49</td>
<td>09.73</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% MS</td>
<td>58.34</td>
<td>51.92</td>
<td>52.70</td>
<td>52.15</td>
<td>11.00</td>
<td>09.66</td>
<td>10.61</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>56.95</td>
<td>50.50</td>
<td>51.70</td>
<td>51.00</td>
<td>11.32</td>
<td>09.22</td>
<td>10.45</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% MS+SP</td>
<td>62.02</td>
<td>55.50</td>
<td>57.05</td>
<td>56.00</td>
<td>10.35</td>
<td>08.01</td>
<td>09.70</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% MS+SP</td>
<td>64.21</td>
<td>57.85</td>
<td>59.50</td>
<td>58.85</td>
<td>09.90</td>
<td>07.33</td>
<td>08.35</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% MS+SP</td>
<td>60.94</td>
<td>55.00</td>
<td>56.00</td>
<td>55.78</td>
<td>09.70</td>
<td>08.10</td>
<td>08.46</td>
</tr>
</tbody>
</table>
Fig. 5.21 Comparison of Compressive Strength with Portland Slag Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Microsilica
Table 5.13 Permeability of Chloride in Portland Slag Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Microsilica

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Cement+Admixture</th>
<th>I₀</th>
<th>I₃₀</th>
<th>I₆₀</th>
<th>I₉₀</th>
<th>I₁₂₀</th>
<th>I₁₅₀</th>
<th>I₁₈₀</th>
<th>I₂₁₀</th>
<th>I₂₄₀</th>
<th>I₂₇₀</th>
<th>I₃₀₀</th>
<th>I₃₃₀</th>
<th>I₃₆₀</th>
<th>ICUMULATIVE in mA</th>
<th>IVERAGE in Coulombs</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>11</td>
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<td>14</td>
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<td>17</td>
<td>2.76</td>
<td>2484</td>
<td></td>
<td>MODERATE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% MS</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>17</td>
<td>17</td>
<td>19</td>
<td>2.98</td>
<td>2682</td>
<td>MODERATE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% MS</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>11</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>19</td>
<td>1.85</td>
<td>1665</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% MS</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>1.35</td>
<td>1215</td>
<td>LOW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>1.39</td>
<td>1251</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% MS+SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<td>9</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>1.26</td>
<td>1134</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10%MS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.45</td>
<td>405</td>
<td>VERY LOW</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% MS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>0.36</td>
<td>324</td>
<td>VERY LOW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From the Table 5.12 the loss in the compressive strength values for the mortar cubes prepared by portland slag cement are 12.77%, 10.04% and 11.49% after acid, alkaline and sulphate tests respectively. Hence the resistance offered is of the order alkaline greater than sulphate greater than acid attack. The remaining all combinations i.e. portland slag cement with partial replacement by 5%, 10% and 15% microsilica both with and without the addition of superplasticizer followed the same pattern of resistance respectively. But a slight increase in the percentage loss in compressive strengths occurred when the replacement of microsilica increased to 15% both without and with the presence of superplasticizer. So, 10% replacement can be considered as an optimum level of replacement among 5%, 10% and 15% replacements.

The effect of chloride ion penetrability is tested by using rapid chloride permeability test (RCPT) and the results are presented in Table 5.13. These results showed that for the mortar cubes prepared by only portland slag cement showed a moderate resistance to chloride ions penetration, 2484 coulombs of charge is passed through the cubes. With the partial replacement of cement by 5% microsilica, the charge passing through the cubes is increased, but still it is in the range of moderate penetration of chloride ions. With the further increase in the percentage of microsilica replacement this resistance offered is increased which is indicated by low penetrability. By the addition of superplasticizer the resistance offered is increased showing lower penetration of chloride ions. With the further increase in the percentage replacement of microsilica along with the superplasticizer, the charge passing through is much more reduced to 324 coulombs, indicating very low penetrability which implies greater resistance to chloride ion penetration. The main reason that can be attributed to reduced permeability is that addition of microsilica causes considerable pore reinforcement i.e. transformation of bigger pores into smaller ones due to the pozzolanic reaction concurrent with cement hydration. Similar type of reduction in chloride ion penetration was reported by Perraton et al. (1988).

5.3.3.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for portland slag cement with 15% replacement by microsilica without and with superplasticizer are presented in Fig. 5.22 and Fig. 5.23 respectively. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of portland slag cement with partial replacement by microsilica without and with superplasticizer are presented in Fig. 5.24.
Fig. 5.22 Results of SEM and EDS - Portland Slag Cement + Microsilica

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>60.77</td>
<td>76.87</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.86</td>
<td>0.72</td>
</tr>
<tr>
<td>Al K</td>
<td>3.81</td>
<td>2.85</td>
</tr>
<tr>
<td>Si K</td>
<td>10.30</td>
<td>7.42</td>
</tr>
<tr>
<td>S K</td>
<td>0.75</td>
<td>0.47</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.17</td>
<td>0.10</td>
</tr>
<tr>
<td>K K</td>
<td>0.70</td>
<td>0.36</td>
</tr>
<tr>
<td>Ca K</td>
<td>20.99</td>
<td>10.60</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.21</td>
<td>0.09</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.46</td>
<td>0.53</td>
</tr>
<tr>
<td>Totals</td>
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<td></td>
</tr>
<tr>
<td>Element</td>
<td>Weight%</td>
<td>Atomic%</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>O K</td>
<td>27.79</td>
<td>51.09</td>
</tr>
<tr>
<td>Na K</td>
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<td>1.24</td>
</tr>
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<td>Mg K</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>Al K</td>
<td>6.92</td>
<td>7.54</td>
</tr>
<tr>
<td>Si K</td>
<td>14.04</td>
<td>14.70</td>
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<tr>
<td>P K</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>K K</td>
<td>0.37</td>
<td>0.28</td>
</tr>
<tr>
<td>Ca K</td>
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<td>Cr K</td>
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</tr>
<tr>
<td>Mn K</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>Fe K</td>
<td>18.79</td>
<td>9.89</td>
</tr>
<tr>
<td>Pd L</td>
<td>2.32</td>
<td>0.64</td>
</tr>
<tr>
<td>Au M</td>
<td>10.69</td>
<td>1.60</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.23 Results of SEM and EDS - Portland Slag Cement + Microsilica+ Superplasticizer
Fig. 5.24 XRD Results for Portland Slag Cement with Partial Replacement by Microsilica
The micrograph referred in Fig. 5.22 reveals that when the partial replacement of portland slag cement with microsilica is done, the cement mortar particles presents a partly discernable particle system with transassemblages with regular connectors and formation of interspaces which shows flakey arrangements with transassemblage system when superplasticizer is also present in the mortar, which is as presented in Fig. 5.23.

From the results presented in Fig. 5.22 and Fig. 5.23 the elements which are present in maximum quantities are identified which are oxygen, calcium, silica, aluminum and iron and few more elements follows in small quantities.

From the XRD results presented in Table 5.5, monoclinic structure is exhibited by the samples prepared from mortar cubes of portland slag cement with partial replacement by microsilica without superplasticizer and with superplasticizer this is changed to orthorhombic with possible compound as calcium silicate and calcium sulphate respectively and in both the cases 2θ angle is around 26° which are identified by matching the results obtained with standard JCPDS data with the peaks present in Fig. 5.24.

At small replacements of portland slag cement by 5%, 10% and 15% without superplasticizer a slight increase in the setting times has occurred and with the addition of the superplasticizer a more retardation appeared in the setting times which are also leading to significant changes some times and all the samples prepared by different combinations of microsilica are sound enough. The compressive strengths at different ages increased up to 10% replacement and then decreased with the increase in the dosage of replacement to 15%. Similar changes occurred when tested for durability by finding the percentage weight loss and loss in the compressive strengths after acid, alkaline and sulphate attacks. These changes may be occurring because of the formation of regular connectors and interspaces which shows flakey arrangements which are identified in SEM analysis and change of monoclinic structure to orthorhombic and formation of compounds such as calcium silicate and calcium sulphate which are presented in XRD results also. So, 10% replacement by microsilica can be considered as an optimum dosage replacement among 5%, 10% and 15% replacement levels.
5.3.4 EFFECT OF RICE HUSK ASH ON DIFFERENT PROPERTIES OF PORTLAND SLAG CEMENT

5.3.4.1 Mechanical Properties

The various mechanical properties such as initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths with partial replacement of portland slag cement by 5%, 10% and 15% replacement by rice husk ash at different ages are presented in Table 5.14 and variations of setting times, compressive strength and percentage change in compressive strength are presented in graphical form in Fig. 5.25, Fig. 5.26(a) and Fig. 5.26(b) respectively.

**Initial and Final Setting Times**

From the Table 5.14 and Fig. 5.25 it is observed that both the initial final setting times got accelerated by partial replacement of rice husk ash in portland slag cement both in the cases of samples without and with superplasticizer more or less in all the cases.

The initial setting times diminished by an amount of 8, 13 and 18 minutes by partial replacement of portland slag cement by 5%, 10%, 15% respectively without superplasticizer. Whereas a slight increase of 2 and 5 minutes appeared with the addition of superplasticizer and 5% replacement of rice husk ash with the presence of superplasticizer, a decrease of 5, and 17 minutes is observed in the case of mortar cubes prepared by partial replacement by 10%, 15% with rice husk ash with the presence of superplasticizer. The change is considered as insignificant in all the combinations as it is not exceeding 30 minutes.

A slight retardation of 8 minutes is identified with partial replacement by 5% rice husk ash and an acceleration in the final setting times by an amount of 6 and 9 minutes in samples without superplasticizer with 10% and 15% replacement and with the addition of the superplasticizer and partial replacement by 5% rice husk ash 18 and 8 minutes increase is appeared respectively and a change of 2 and 7 minutes acceleration is also observed in the case of samples with partial replacement by 10% and 15% with the presence of superplasticizer, which is also considered as insignificant change.
Table 5.14  Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>133</td>
<td>217</td>
<td>0.90</td>
<td>22.50</td>
<td>26.20</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC + 5% RHA</td>
<td>125</td>
<td>225</td>
<td>1.0</td>
<td>23.72</td>
<td>27.85</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC + 10% RHA</td>
<td>120</td>
<td>211</td>
<td>0.80</td>
<td>23.87</td>
<td>27.90</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC + 15% RHA</td>
<td>115</td>
<td>208</td>
<td>0.85</td>
<td>22.80</td>
<td>26.64</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC + SP</td>
<td>135</td>
<td>235</td>
<td>0.67</td>
<td>22.99</td>
<td>28.84</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC + 5% RHA + SP</td>
<td>138</td>
<td>225</td>
<td>0.68</td>
<td>23.05</td>
<td>28.94</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC + 10% RHA + SP</td>
<td>128</td>
<td>215</td>
<td>0.88</td>
<td>23.58</td>
<td>29.20</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC + 15% RHA + SP</td>
<td>116</td>
<td>210</td>
<td>0.80</td>
<td>23.04</td>
<td>27.00</td>
</tr>
</tbody>
</table>
Fig. 5.25 Variation of Initial and Final Setting Times with Partial Replacement of Portland Slag Cement by Rice Husk Ash
Fig. 5.26(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Portland Slag Cement
So, early setting times are observed in most of the cases with partial replacement of portland slag cement with rice husk ash than that of sample prepared with only portland slag cement. Sensale et al. (2008) investigated the influence of partial replacement of portland cement by rice husk ash on setting times of cement paste and concluded that setting times decreased with increase in the rice husk ash content. These are same as the observations done in the present investigation also.

**Soundness Test Results**

Soundness test results of the samples made with partial replacement of portland slag cement by rice husk ash are presented in the Table 5.1. and these values ranges between 0.67 mm to 1.0 mm. But these variations are considered as meager when compared to the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples both in the case of the samples prepared with and without the combination of superplasticizer.

**Compressive Strength**

From Table 5.14 and Fig. 5.26(a) it can be observed that inclusion of rice husk ash as partial replacement of portland slag cement enhances the compressive strength up to a certain replacement dosage then with the further increase in the rice husk ash percentage replacement the compressive strength diminishes. This type of increase is observed up to 10% replacement and then it decreased with 15% replacement at all ages and even significant reduction in the strengths is observed after certain days both in the case of mortar cubes with and without superplasticizer which can be identified from Fig. 5.26(b). A significant reduction in the compressive strength of -10% to -12% can be noticed at 15% replacement dosage both in the case of mortar cubes prepared without and with the presence of the superplasticizer.

Addition of RHA caused an increase in the compressive strength due to pozzolanic action of rice husk ash. So, it can be concluded that 10% replacement can be treated as optimum dosage of percentage replacement among 5%, 10% and 15% replacement levels. Similar conclusions were drawn by Zhang et al. (1996) from their investigations suggested that 10% RHA replacement exhibited upper strength than control mortar cubes at all ages.
5.3.4.2 Durability Properties

Just as in the previous cases before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage weight loss when compared to the control mix samples are calculated. The effect of Rice Husk Ash on partial replacement of portland slag cement are presented in Table 5.15 and in Fig. 5.27.

From the Table 5.15 and Fig. 5.27 a weight loss of 2.3%, 2.15% and 2.20% against acid attack was exhibited by the mortar cubes prepared by partial replacement of portland slag cement by 5%, 10% and 15% respectively without superplasticizer. Mortar cubes prepared with the presence of superplasticizer and only portland slag cement showed a weight loss of 2.25% where as a weight loss of 2.10%, 1.95% and 2.05% are resulted with 5%, 10% and 15% replacement of rice husk ash with the presence of superplasticizer respectively against acid attack.

Table 5.15 Effect of Rice Husk Ash Replacement on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Percentage Loss in Weight after 60 Days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>2.40</td>
</tr>
<tr>
<td>2</td>
<td>95%PSC +5% RHA</td>
<td>2.30</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% RHA</td>
<td>2.15</td>
</tr>
<tr>
<td>4</td>
<td>85%PSC +15% RHA</td>
<td>2.20</td>
</tr>
<tr>
<td>5</td>
<td>100%PSC +SP</td>
<td>2.25</td>
</tr>
<tr>
<td>6</td>
<td>95%PSC +5% RHA+SP</td>
<td>2.10</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% RHA+SP</td>
<td>1.95</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% RHA+SP</td>
<td>2.05</td>
</tr>
</tbody>
</table>
Various Combinations of Portland Slag Cement with Rice Husk Ash

Fig. 5.27 Effect of Rice Husk Ash on Portland Slag Cement without and with Superplasticizer on Percentage Weight Loss

Against alkaline attack a weight loss of 1.5%, 1.4% and 1.45% was noticed for the mortar cubes prepared by partial replacement of portland slag cement by rice husk ash without superplasticizer. For mortar cubes with superplasticizer presence and only portland slag cement a weight loss of 1.50% was recognized whereas a weight loss of 1.45%, 1.30% and 1.35% was identified with partial replacement by rice husk ash with superplasticizer presence.

A weight loss of 1.7%, 1.64% and 1.66% against sulphate attack was exhibited by the cubes prepared by partial replacement of portland slag cement by 5%, 10% and 15% respectively. For the cubes prepared by only portland slag cement with the addition of superplasticizer a weight loss of 1.68% was occurred, whereas a loss of 1.50%, 1.35% and 1.40% appeared in the case of partial replacement with 5%, 10% and 15% replacement along with the addition of superplasticizer.

By observation it can be identified that weight reduction in the mortar cubes prepared with various combinations of rice husk ash exhibited reduction up to 10% replacement only, both without and with superplasticizer presence which implies that according to the investigations 10% replacement level can be considered as optimum among 5%, 10% and 15% replacement levels.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 days) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>54.80</td>
<td>47.80</td>
<td>49.30</td>
<td>48.50</td>
<td>12.77</td>
<td>10.04</td>
<td>11.49</td>
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<td>2</td>
<td>95%PSC +5% RHA</td>
<td>56.80</td>
<td>50.45</td>
<td>51.20</td>
<td>50.90</td>
<td>11.18</td>
<td>09.86</td>
<td>10.39</td>
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<td>90%PSC +10% RHA</td>
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<td>52.60</td>
<td>53.25</td>
<td>52.80</td>
<td>10.51</td>
<td>09.41</td>
<td>10.17</td>
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<td>09.59</td>
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<td>11.32</td>
<td>09.22</td>
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</tr>
<tr>
<td>7</td>
<td>90%PSC +10% RHA +SP</td>
<td>61.15</td>
<td>55.85</td>
<td>55.91</td>
<td>55.90</td>
<td>08.67</td>
<td>06.93</td>
<td>08.58</td>
</tr>
<tr>
<td>8</td>
<td>85%PSC +15% RHA +SP</td>
<td>53.5</td>
<td>52.90</td>
<td>53.10</td>
<td>53.00</td>
<td>11.21</td>
<td>07.47</td>
<td>09.34</td>
</tr>
</tbody>
</table>
Fig. 5.28  Comparison of Compressive Strength with Portland Slag Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Rice Husk Ash
Table 5.17  Permeability of Chloride in Portland Slag Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Rice Husk Ash

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement+ Admixture</th>
<th>I_30</th>
<th>I_60</th>
<th>I_90</th>
<th>I_120</th>
<th>I_150</th>
<th>I_180</th>
<th>I_210</th>
<th>I_240</th>
<th>I_270</th>
<th>I_300</th>
<th>I_330</th>
<th>I_360</th>
<th>I_{CUMULATIVE} in mA</th>
<th>I_{AVERAGE} in Coulombs</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% PSC</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>14</td>
<td>14</td>
<td>17</td>
<td>17</td>
<td></td>
<td>2.76</td>
<td>2484</td>
<td>MODERATE</td>
</tr>
<tr>
<td>2</td>
<td>95% PSC + 5% RHA</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>19</td>
<td>21</td>
<td>24</td>
<td>24</td>
<td>3.92</td>
<td>3528</td>
<td>MODERATE</td>
</tr>
<tr>
<td>3</td>
<td>90% PSC + 10% RHA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>1.62</td>
<td>1458</td>
<td>LOW</td>
</tr>
<tr>
<td>4</td>
<td>85% PSC + 15% RHA</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>13</td>
<td>13</td>
<td>2.03</td>
<td>1827</td>
<td>LOW</td>
</tr>
<tr>
<td>5</td>
<td>100% PSC + SP</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>8</td>
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<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>1.39</td>
<td>1251</td>
<td>LOW</td>
</tr>
<tr>
<td>6</td>
<td>95% PSC + 5% RHA + SP</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td></td>
<td>1.82</td>
<td>1638</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>90% PSC + 10% RHA + SP</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>12</td>
<td></td>
<td>1.36</td>
<td>1224</td>
<td>LOW</td>
</tr>
<tr>
<td>8</td>
<td>85% PSC + 15% RHA + SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td></td>
<td>0.90</td>
<td>810</td>
<td>VERY LOW</td>
</tr>
</tbody>
</table>

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The effect of partial replacement of rice husk ash on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.16 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.17 for portland slag cement. The variation of the compressive strength values at 90 days are compared with acid, alkaline and sulphate test and are presented in Fig. 5.28. As already presented in the previous discussions, more percentage loss in compressive strength indicates that less resistance is offered by the mortar cubes to that particular attack.

Percentage loss in compressive strength after acid, alkaline, sulphate test are 12.77%, 10.04% and 11.49% respectively for the mortar cubes prepared by only portland slag cement, which can be observed from the Table 5.16. This shows that these cubes offer much resistance to alkaline followed by sulphate and then by acid attacks.

The remaining all combinations of mortar cubes prepared by partial replacement by 5%, 10% and 15% of rice husk ash both without and with the presence of superplasticizer and cubes prepared by portland slag cement with superplasticizer exhibit resistance of the similar order. But the resistance offered by the cubes prepared with 15% replacement is less when compared to 5% and 10% replacement levels. So, 15% replacement can be discarded and 10% replacement can be considered as optimum. Out of all combinations 10% replacement by rice husk ash along with the presence of superplasticizer can be considered as the best.

The results of the study made by Sakr (2006) revealed that partial replacement with RHA had good resistance to sulphate attack which is one of the important aspects of durability.

From Table 5.17 it can be understood that mortar cubes of only portland slag cement and 5% replacement by rice husk ash are exhibiting moderate penetrability of chloride ions where as in the other combinations the penetrability is low with the increase in the dosage of rice husk ash.

The passage of charge is only 810 coulombs in the cubes prepared by 15% replacement by rice husk ash with superplasticizer, and this value is in the range of very low penetrability according to rapid chloride permeability test results. So, it can be
concluded that this is the best combination. But according to durability test results 15% replacement is not offering much resistance to acid, alkaline and sulphate tests than 10% replacement. So, 10% rice husk ash replacement can be treated as optimum dosage replacement.

Zhang and Malhotra (1996), Anwar et al. (2001) and Nahdi et al. (2003) concluded from their investigations that there are significant reductions in chloride ions permeability from moderate rating to low and very low ratings due to replacement of cement with rice husk ash. Similar types of results are exhibited from the present investigations also.

The results of the various durability tests conducted revealed that the mortar cubes prepared by partial replacement by rice husk ash up to 10% exhibited enhanced resistance to various attacks like acid attack, alkaline attack, sulphate attack and chloride attack.

5.3.4.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for portland slag cement with and without superplasticizer are presented in Fig. 5.29 and Fig. 5.30. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of portland slag cement with partial replacement by rice husk ash with and without superplasticizer are presented in Fig. 5.31. XRD results of ordinary portland cement are presented in Table 5.5.

The micrograph for partial replacement of portland slag cement by rice husk ash is presented in Fig. 5.29 and with superplasticizer is presented in Fig. 5.30 which shows the formation of cement mortar with RHA particles in to matrix assemblage with interweaving bunches and interconnected edge to edge formation of interspaces. Sheets like structure with flaky arrangements of the particles are identified. These figures shows that the pore spaces are reduced with the addition of rice husk ash.

The various elements present in the mortar cubes are identified and presented in the SEM results in Fig. 5.29 and Fig. 5.30. The elements present in major quantities are oxygen, calcium, silica, aluminium and iron and small traces of some other elements.
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C K</td>
<td>12.36</td>
<td>19.12</td>
</tr>
<tr>
<td>O K</td>
<td>53.78</td>
<td>62.47</td>
</tr>
<tr>
<td>Na K</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.69</td>
<td>0.52</td>
</tr>
<tr>
<td>Al K</td>
<td>3.23</td>
<td>2.22</td>
</tr>
<tr>
<td>Si K</td>
<td>8.73</td>
<td>5.78</td>
</tr>
<tr>
<td>S K</td>
<td>0.63</td>
<td>0.37</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>K K</td>
<td>0.60</td>
<td>0.29</td>
</tr>
<tr>
<td>Ca K</td>
<td>18.20</td>
<td>8.44</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.27</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.29 Results of SEM and EDS - Portland Slag Cement + Rice Husk Ash
Fig. 5.30 Results of SEM and EDS - Portland Slag Cement + Rice Husk Ash + Superplasticizer

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>48.99</td>
<td>65.87</td>
</tr>
<tr>
<td>Na K</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.56</td>
<td>0.50</td>
</tr>
<tr>
<td>Al K</td>
<td>2.30</td>
<td>1.83</td>
</tr>
<tr>
<td>Si K</td>
<td>27.19</td>
<td>20.83</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>K K</td>
<td>0.70</td>
<td>0.39</td>
</tr>
<tr>
<td>Ca K</td>
<td>18.16</td>
<td>9.75</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.18</td>
<td>0.08</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.86</td>
<td>0.72</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100.00</strong></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5.31 XRD Results for Portland Slag Cement with Partial Replacement by Rice Husk Ash
From the XRD results presented in Table 5.5 and they show that the anorthic structure is changed to orthorhombic with the inclusion of superplasticizer with replacement of portland slag cement by 15% rice husk ash by weight and the 2θ angle is around 26° in both the cases, as shown in Fig. 5.31 and which are identified by comparing the results with standard JCPDS data where as the major compounds formed are hematite and mullite respectively.

The setting times decreased with the increase in the rice husk ash content and all the samples prepared by various combinations of rice husk ash are sound enough for usage. The addition of rice husk ash as partial replacement enhanced the compressive strengths up to 10% replacement levels which started depleting with the further increase in the dosage of rice husk ash. Similar results were exhibited in the durability aspects also. This may be all because of reduction in the pore spaces with the addition of rice husk ash at initial levels which was presented in SEM analysis also and the structure also changed from anorthic to orthorhombic with the formation of compounds such as hematite and mullite majorly.

5.4 RESULTS OF THE EXPERIMENTAL INVESTIGATIONS AND DISCUSSIONS WITH PARTIAL REPLACEMENT OF ORDINARY PORTLAND CEMENT BY DIFFERENT ADMIXTURES

Fly ash, Ground granulated blast furnace slag, Microsilica and Rice husk ash are the mineral admixtures used and superplasticizer as chemical admixture is used in the present investigation as partial replacement of ordinary portland cement. The results of various investigations are presented and discussed in detail, which are as follows:

5.4.1 EFFECT OF FLY ASH ON DIFFERENT PROPERTIES OF ORDINARY PORTLAND CEMENT

5.4.1.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of cement samples with 5%, 10% and 15% partial replacement of ordinary portland cement by fly ash with and without chemical admixture are presented in the Table 5.18 and the variations of setting times with partial replacement of ordinary portland cement by fly ash and variations of compressive strengths and percentage change in compressive strengths are presented graphically in Fig. 5.32 Fig. 5.33(a) and Fig. 5.33(b) respectively.
Table 5.18  Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Fly Ash without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>123</td>
<td>218</td>
<td>0.77</td>
<td>23.60</td>
<td>33.90</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% FA</td>
<td>138</td>
<td>225</td>
<td>0.80</td>
<td>23.88</td>
<td>35.18</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% FA</td>
<td>139</td>
<td>230</td>
<td>0.82</td>
<td>25.66</td>
<td>36.46</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% FA</td>
<td>140</td>
<td>244</td>
<td>0.89</td>
<td>25.19</td>
<td>36.47</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>135</td>
<td>240</td>
<td>0.88</td>
<td>24.90</td>
<td>35.43</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% FA+SP</td>
<td>128</td>
<td>230</td>
<td>0.90</td>
<td>25.84</td>
<td>36.89</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% FA+SP</td>
<td>138</td>
<td>245</td>
<td>0.93</td>
<td>27.12</td>
<td>37.86</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% FA+SP</td>
<td>145</td>
<td>256</td>
<td>0.95</td>
<td>26.32</td>
<td>37.50</td>
</tr>
</tbody>
</table>
Fig. 5.32 Variation of Initial and Final Setting Time with Partial Replacement of Ordinary Portland Cement by Fly Ash
Fig. 5.33(a)  Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Fly Ash without and with Superplasticizer in Ordinary Portland Cement
Fig. 5.33(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Fly Ash without and with Superplasticizer in Ordinary Portland Cement
**Initial and Final Setting Times**

The initial setting times show a very slight retardation with the partial replacement of cement by fly ash at different dosages of 5%, 10% and 15% without the presence of superplasticizer in ordinary portland cement which are 15, 16 and 17 minutes respectively. The change in these initial setting times is considered as insignificant as these values are slightly more than that of the ordinary portland cement. Similarly retardation in the final setting times is also observed which are 7, 12 and 26 minutes more than that of the ordinary portland cement samples respectively and these changes are also considered as insignificant.

The initial setting times of ordinary portland cement with the addition of the superplasticizer showed a delay of 12 minutes and various other combinations prepared by partial replacement of ordinary portland cement by fly ash by 5%, 10% and 15% along with superplasticizer showed a delay of 5, 15 and 22 minutes respectively. These changes are considered as insignificant. Similarly final setting times also retarded by an amount of 22 minutes with the addition of the superplasticizer to ordinary portland cement. The combinations prepared by partial replacement by 5%, 10% and 15% fly ash showed a delay of 12, 27 and 38 minutes respectively. Here for 15% replacement along with superplasticizer showed a significant change. Similar to the results obtained, Ramakrishna et al. (1981) also specified that an increase in the setting times occurred with the use of fly ash.

This delay in the setting times may be due to the formation of dense structure with the addition of the fly ash which are also presented in the SEM micrographs as formations of flocculation of the ingredients and hydration reaction products which results in the formation of strong bond may be in the form of calcium silicate and calcium aluminium silicate compounds.

**Soundness Test Results**

Soundness test results of the samples made with ordinary portland cement are presented in the Tables 5.18 and the soundness values ranges from 0.77 to 0.95 mm. But this variation is very meager and less than the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples is observed both in the case of the samples prepared with and without the combination of superplasticizer and finally the samples prepared are considered to be sound.
Compressive Strength

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of fly ash without and with superplasticizer in ordinary portland cement along with the percentage change in the compressive strength are presented in Table 5.18 and Fig. 5.33(a) and Fig. 5.33(b) shows the variations in the compressive strengths and percentage change in the compressive strengths at different ages with different dosages.

From Table 5.18 and Fig. 5.33(a) it can be observed that the compressive strength continued to increase with age, indicating the pozzolanic action of fly ash as most of the researchers concluded from their investigations as explained in the literature review, and this holds good only up to an optimum dosage of replacement of ordinary portland cement by fly ash.

No remarkable increase in the compressive strength is observed at early ages i.e., at 3 days and 7 days, and eventually, greater strength gaining characteristic is observed at the later ages up to one year. The compressive strength observed at an age of 365 days is almost three times that of the 3 days compressive strength almost in all the combinations of fly ash with and without superplasticizer.

The percentage change in the compressive strength is represented in graphical form in Fig. 5.33(b) which reveals that a significant change occurred at all ages in the mortar cubes prepared by 10% and 15% replacement by fly ash with the presence of superplasticizer. This may be due to the enhancement in the bondage with the addition of the fly ash to ordinary portland cement.

Moinul Islam and Saiful Islam (2010) and Karim et al. (2011) studied the influence of fly ash on the strength development of mortar cubes of ordinary portland cement and concluded that strength development has increased up to an optimum dosage.

5.4.1.2 Durability Properties

Similar to the previous cases here also before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the percentage weight loss when compared to the control mix mortar cubes are calculated. The effect
of Fly Ash on partial replacement of ordinary portland cement is presented in Table 5.19 and in Fig. 5.34.

Table 5.19 Effect of Fly Ash Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Percentage Loss in Weight after 60 Days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100% OPC</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>95% OPC +5% FA</td>
<td>1.90</td>
</tr>
<tr>
<td>3</td>
<td>90% OPC +10% FA</td>
<td>1.70</td>
</tr>
<tr>
<td>4</td>
<td>85% OPC +15% FA</td>
<td>1.68</td>
</tr>
<tr>
<td>5</td>
<td>100% OPC +SP</td>
<td>1.70</td>
</tr>
<tr>
<td>6</td>
<td>95% OPC +5%FA+SP</td>
<td>1.60</td>
</tr>
<tr>
<td>7</td>
<td>90% OPC +10% FA+SP</td>
<td>1.55</td>
</tr>
<tr>
<td>8</td>
<td>85% OPC +15% FA+SP</td>
<td>1.46</td>
</tr>
</tbody>
</table>

Fig. 5.34 Effect of Fly Ash Replacement on Ordinary Portland Cement without and with Superplastizer on Percentage Weight Loss

From the Table 5.19 and Fig. 5.34 it is clearly recognized that the percentage loss in weight due to acid attack on mortar cubes prepared by 5%, 10% and 15% replacement of ordinary portland cement by fly ash are 1.9%, 1.7% and 1.68% respectively. When superplasticizer is added to ordinary portland cement a weight loss
of 1.7% is observed and with 5%, 10% and 15% replacement along with superplasticizer a loss in weight of 1.6%, 1.55% and 1.46% respectively. With the addition of fly ash with increased percentages a decreasing trend is observed in the weight loss both without and with the presence of superplasticizer.

In the similar style a decreasing trend in the weight losses is observed in the case of alkaline attack which are in the order 0.97%, 0.90% and 0.82% respectively in the mortar cubes prepared by partial replacement of ordinary portland cement by 5%, 10% and 15% by fly ash and with the presence of superplasticizer this changed from 1.22% to 1.10% followed by 1.05% and 1.0% respectively.

Similar trend of decreasing weight loss is presented after sulphate attack also by the mortar cubes without addition of superplasticizer which are as follows 1.2%, 1.15%, and 1.08% and with the addition of superplasticizer this decreasing trend is represented as 1.42%, which further reduced to 1.3%, then to 1.26% and then followed by 1.2% respectively.

From the above mentioned results it can be clear that the mortar cubes are losing their weights after immersion in different acid, alkaline and sulphate solutions which reveals their reduction in capacity of resistance. It can be noticed from the graphical representation that the mortar cubes are showing much resistance to alkaline attack followed by sulphate attack and finally showing less resistance against acid attack.

The effect of fly ash on different durability tests such as acid test, alkaline test and sulphate test after 60 days immersion in the respective samples along with percentage loss in compressive strength are presented in Table 5.20 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.21 for ordinary portland cement. The variation of the compressive strength values at 90 day are compared to acid, alkaline and sulphate test and are presented in Fig. 5.35.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>48.20</td>
<td>41.20</td>
<td>42.90</td>
<td>41.80</td>
<td>14.52</td>
<td>10.99</td>
<td>13.28</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% FA</td>
<td>51.52</td>
<td>44.80</td>
<td>45.70</td>
<td>45.30</td>
<td>13.04</td>
<td>11.30</td>
<td>12.00</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% FA</td>
<td>50.21</td>
<td>43.80</td>
<td>44.35</td>
<td>44.15</td>
<td>12.76</td>
<td>11.68</td>
<td>12.07</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% FA</td>
<td>51.04</td>
<td>44.25</td>
<td>45.94</td>
<td>44.82</td>
<td>13.30</td>
<td>10.00</td>
<td>12.18</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>50.24</td>
<td>43.50</td>
<td>44.60</td>
<td>44.10</td>
<td>13.42</td>
<td>11.23</td>
<td>12.22</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% FA+SP</td>
<td>51.85</td>
<td>44.30</td>
<td>45.50</td>
<td>44.70</td>
<td>14.56</td>
<td>12.24</td>
<td>13.78</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% FA+SP</td>
<td>53.70</td>
<td>46.20</td>
<td>47.35</td>
<td>46.30</td>
<td>13.96</td>
<td>11.82</td>
<td>13.78</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% FA+SP</td>
<td>54.73</td>
<td>47.43</td>
<td>48.72</td>
<td>48.32</td>
<td>13.34</td>
<td>10.98</td>
<td>11.72</td>
</tr>
</tbody>
</table>
Differences in Compressive Strength with Ordinary Portland Cement at 90 Day vs Acid, Alkaline and Subphosphate Tests with Various Combinations of Ordinary Portland Cement with Fly Ash

85% OPC + 15% FA+SP
90% OPC + 10% FA+SP
95% OPC + 5% FA+SP
100% OPC + 0% FA
85% OPC + 5% FA
90% OPC + 10% FA
55% OPC + 5% FA
100% OPC

Compressive Strength (MPa)
Table 5.21 Permeability of Chloride in Ordinary Portland Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Fly Ash

<table>
<thead>
<tr>
<th>S.No</th>
<th>Cement+ Admixture</th>
<th>I₀</th>
<th>I₃₀</th>
<th>I₆₀</th>
<th>I₁₂₀</th>
<th>I₁₈₀</th>
<th>I₂₄₀</th>
<th>I₃₀₀</th>
<th>I₃₆₀</th>
<th>I₅₀₀</th>
<th>I₇₂₀</th>
<th>I₉₆₀</th>
<th>I₁₀₈₀</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>2.30</td>
<td>2070</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% FA</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>16</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% FA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>19</td>
<td>1.93</td>
<td>1737</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% FA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>0.65</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>17</td>
<td>19</td>
<td>2.73</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% FA +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>1.54</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% FA +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>2.04</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% FA +SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>0.62</td>
<td>556</td>
</tr>
</tbody>
</table>
Based on the results presented in the Table 5.20 and Fig. 5.35 the mortar cubes prepared by ordinary portland cement showed a percentage loss of 14.52, 10.99 and 13.28 for acid, alkaline and sulphate resistance attack tests respectively, which depicts that the mortar cubes showed greater resistance to alkaline than sulphate than acid attacks. Similar is the trend followed by the mortar cubes prepared by different replacement dosages of ordinary portland cement by fly ash without and with the superplasticizer.

For the samples prepared by different levels of fly ash replacement dosages i.e., 5%, 10% and 15% the percentage loss in compressive strengths started declining, which in turn implies that greater resistance offering characteristic is appeared with the increase in the amount of fly ash replacement against acid, alkaline and sulphate attacks.

The rapid chloride permeability test results presented in Table 5.21 depicts that the mortar cubes prepare by ordinary portland cement with and without superplasticizer and 5% fly ash with superplasticizer showed moderate chloride permeability, where as the combinations of OPC with 10% fly ash with and without superplasticizer and OPC with 5% fly ash replacement along with the superplasticizer showed low permeability to chloride ion permeability and the mortar cubes prepared by 15% fly ash replacement with and without superplasticizer showed very low permeability to chloride ions.

From the rapid chloride permeability test results it can be understood that with the increase in the percentage replacement of ordinary portland cement by fly ash, the resistance offered to chloride permeability is getting enhanced which is identified with change in the levels of penetrability of chloride ions from moderate to low and then to very low.

5.4.1.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for ordinary portland cement and ordinary portland cement with 15% fly ash with and without superplasticizer are presented in Fig. 5.36 to Fig. 5.39. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of ordinary portland cement with partial replacement by fly ash with and without superplasticizer are presented in Fig. 5.40 and Fig. 5.41. XRD results of ordinary portland cement are presented in Table 5.22.
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>52.73</td>
<td>69.50</td>
</tr>
<tr>
<td>Na K</td>
<td>2.20</td>
<td>2.02</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.41</td>
<td>0.36</td>
</tr>
<tr>
<td>Al K</td>
<td>5.25</td>
<td>4.10</td>
</tr>
<tr>
<td>Si K</td>
<td>15.20</td>
<td>11.41</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.28</td>
<td>0.17</td>
</tr>
<tr>
<td>K K</td>
<td>1.73</td>
<td>0.94</td>
</tr>
<tr>
<td>Ca K</td>
<td>21.05</td>
<td>11.07</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.14</td>
<td>0.43</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.36 Results of SEM and EDS - Ordinary Portland Cement
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>64.47</td>
<td>78.84</td>
</tr>
<tr>
<td>Mg K</td>
<td>2.16</td>
<td>1.74</td>
</tr>
<tr>
<td>Al K</td>
<td>4.40</td>
<td>3.19</td>
</tr>
<tr>
<td>Si K</td>
<td>9.53</td>
<td>6.64</td>
</tr>
<tr>
<td>Cl K</td>
<td>1.42</td>
<td>0.78</td>
</tr>
<tr>
<td>K K</td>
<td>0.84</td>
<td>0.42</td>
</tr>
<tr>
<td>Ca K</td>
<td>17.17</td>
<td>8.38</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe K</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.37 Results of SEM and EDS - Ordinary Portland Cement + Fly Ash
Element | Weight% | Atomic%
--- | --- | ---
O K | 53.09 | 69.95
Na K | 0.38 | 0.35
Mg K | 0.59 | 0.51
Al K | 4.89 | 3.82
Si K | 18.48 | 13.87
Cl K | 0.20 | 0.12
K K | 4.01 | 2.16
Ca K | 15.33 | 8.06
Ti K | 0.17 | 0.07
Fe K | 2.87 | 1.08

Totals | 100.00

Fig. 5.38 Results of SEM and EDS - Ordinary Portland Cement + Superplasticizer

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<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>52.29</td>
<td>66.56</td>
</tr>
<tr>
<td>Na K</td>
<td>4.52</td>
<td>4.01</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Al K</td>
<td>8.91</td>
<td>6.73</td>
</tr>
<tr>
<td>Si K</td>
<td>24.69</td>
<td>17.90</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>K K</td>
<td>1.76</td>
<td>0.92</td>
</tr>
<tr>
<td>Ca K</td>
<td>6.62</td>
<td>3.36</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe K</td>
<td>0.95</td>
<td>0.34</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.39 Results of SEM and EDS - Ordinary Portland Cement + Superplasticizer + Fly Ash
Fig. 5.40 XRD Results for Control Mixes of Ordinary Portland Cement
Fig. 5.41 XRD Results for Ordinary Portland Cement with Partial Replacement by Fly Ash
Table 5.22 XRD Results for Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>20 Angle (Degrees)</th>
<th>Structure</th>
<th>Wave Length (Å)</th>
<th>Possible Compound</th>
<th>JCPDS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OPC</td>
<td>26.89</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca(SiO₃) Calcium Silicate</td>
<td>89-6463</td>
</tr>
<tr>
<td>2</td>
<td>OPC+FA</td>
<td>26.89</td>
<td>Orthorhombic</td>
<td>1.54178</td>
<td>Al₂SiO₅ Sillimanite, Aluminium Silicate</td>
<td>38-0471</td>
</tr>
<tr>
<td>3</td>
<td>OPC+GGBS</td>
<td>26.5041</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca₃(SiO₄)₃ Calcium Silicate</td>
<td>89-6485</td>
</tr>
<tr>
<td>4</td>
<td>OPC+MS</td>
<td>26.686</td>
<td>Anorthic</td>
<td>1.54060</td>
<td>CaO(Al₂O₃)₂ Calcium Hydroxide (Hematite)</td>
<td>89-8573</td>
</tr>
<tr>
<td>5</td>
<td>OPC+RHA</td>
<td>26.504</td>
<td>Monoclinic</td>
<td>1.5405</td>
<td>CaO(Al₂O₃)₂ Calcium Aluminium Oxide (Mullite)</td>
<td>25-0618</td>
</tr>
<tr>
<td>6</td>
<td>OPC+SP</td>
<td>26.504</td>
<td>Orthorhombic</td>
<td>1.5405</td>
<td>CaAl₂Si₂O₈ Calcium Aluminium Silicate</td>
<td>05-0528</td>
</tr>
<tr>
<td>7</td>
<td>OPC+FA+SP</td>
<td>26.686</td>
<td>Orthorhombic</td>
<td>1.54060</td>
<td>Al₂(SiO₃) Aluminium Silicate</td>
<td>89-0888</td>
</tr>
<tr>
<td>8</td>
<td>OPC+GGBS+SP</td>
<td>26.504</td>
<td>Monoclinic</td>
<td>1.54060</td>
<td>Ca(SiO₃) Calcium Silicate</td>
<td>89-6463</td>
</tr>
<tr>
<td>9</td>
<td>OPC+MS+SP</td>
<td>26.891</td>
<td>Anorthic</td>
<td>1.54060</td>
<td>Ca(Al₂SiO₄) Anorthite, Annealed, Calcium Aluminium Silicate</td>
<td>89-1472</td>
</tr>
<tr>
<td>10</td>
<td>OPC+RHA+SP</td>
<td>26.686</td>
<td>Orthorhombic</td>
<td>1.54056</td>
<td>Al₆Si₄O₁₃ Mullite, Aluminium Silicate</td>
<td>15-0776</td>
</tr>
</tbody>
</table>
The results of SEM and EDS are shown in the Fig. 5.36 to Fig. 5.39. It is clearly seen from the results that the major elements that are found in the samples prepared from various combinations of ordinary portland cement are oxygen, calcium, silica majorly and iron, sodium and potassium are present in little amounts.

The micrograph of ordinary portland cement is presented in Fig. 5.36 which shows crumbs of floccules with connector assemblages. The micrograph of ordinary portland cement and superplasticizer is shown in Fig. 5.38 which reveals the cement mortar and super plasticizer particles are aggregated arrangements due to flocculation of the particles because of formation of strong bond and large mass of cementitious properties of the ingredients present.

The micrograph of ordinary portland cement with partial replacement by fly ash shows aggregated arrangements due to flocculation of cement mortar and formation of hydration reaction products due to more cementitious properties of fly ash which is as shown in Fig. 5.37.

From the XRD results presented in Fig. 5.40 and Fig. 5.41 the peaks can be observed at around $26^\circ$ and by using standard JCPDS data the possible compounds formed are identified. The monoclinic structure of ordinary portland cement is changed into orthorhombic with the addition of fly ash and superplasticizer. Possible compounds formed in the samples of ordinary portland cement, ordinary portland cement with partial replacement by fly ash, ordinary portland cement with fly ash and superplasticizer are calcium silicate, aluminium silicate, calcium aluminium silicate and aluminium silicate respectively which are presented in Table 5.22.

With the increase in the percentage replacement by fly ash an enhancement in the setting times has occurred and also the compressive strengths also increased at all ages and as the age prolongs. The durability of the mortar cubes against various attacks like acid attack, alkaline attack, sulphate attack and chloride attacks also enhanced with the increase in the percentage of fly ash. All these changes may be because of the formation of strong bond between the various ingredients and formation of compounds like sillimanite and aluminium silicate and changing of the structure from monoclinic to orthorhombic and also the formation of C-S-H gel.
5.4.2 EFFECT OF GROUND GRANULATED BLAST FURNACE SLAG ON DIFFERENT PROPERTIES OF ORDINARY PORTLAND CEMENT

5.4.2.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of cement mortar cubes with 5%, 10% and 15% partial replacement of ordinary portland slag cement by ground granulated blast furnace slag without and with superplasticizer are presented in the Table 5.23 and the graphical representation of initial and final setting times and variations of compressive strengths and percentage change in the compressive strengths are shown in Fig. 5.42, Fig. 5.43(a) and Fig. 5.43(b) respectively.

Initial and Final Setting Times

From the Table 5.23 and Fig. 5.42 it is observed that both the initial and final setting times got retarded by partial replacement of ground granulated blast furnace slag in the ordinary portland cement.

The initial setting times of the samples prepared by 5%, 10% and 15% replacement of ordinary portland cement by GGBS without the presence of superplasticizer showed a delay of 20, 22 and 25 minutes respectively. The change in these initial setting times is considered as insignificant as these values are slightly more than that of the ordinary portland cement. Similarly an increase in the final setting times is also observed which are 10, 12 and 17 minutes more than that of the ordinary portland cement samples respectively and these changes are also considered as insignificant.

Both the initial setting times and final setting times for the samples prepared by ordinary portland cement along with superplasticizer showed a delay of 12 and 22 minutes respectively. With the partial replacement of cement by ground granulated blast furnace slag along with superplasticizer show a retardation of 15, 17 and 22 minutes in the initial setting times, whereas a delay of 24, 27 and 30 minutes can be identified in the final setting times. The change in the samples prepared by 5%, 10% and 15% replacement of GGBS along with superplasticizer is also considered as insignificant. The retardation in the setting times may be influenced by the formation of C-S-H gel in the GGBS presence. Wainwright and Ait-Aider (1995) investigated the effect of GGBS on the setting times of cement and concluded that setting times of cement were increased with the increase in GGBS content. These results are same as the results obtained in the present investigation also.
Table 5.23 Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>123</td>
<td>218</td>
<td>0.77</td>
<td>23.60</td>
<td>33.90</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC+5%GGBS</td>
<td>143</td>
<td>228</td>
<td>0.80</td>
<td>25.70</td>
<td>35.96</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC+10%GGBS</td>
<td>145</td>
<td>230</td>
<td>0.95</td>
<td>25.08</td>
<td>36.16</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC+15%GGBS</td>
<td>148</td>
<td>235</td>
<td>0.70</td>
<td>24.49</td>
<td>36.51</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC+SP</td>
<td>135</td>
<td>240</td>
<td>0.88</td>
<td>24.90</td>
<td>35.43</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC+5%GGBS+SP</td>
<td>138</td>
<td>242</td>
<td>0.90</td>
<td>24.85</td>
<td>36.45</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC+10%GGBS+SP</td>
<td>140</td>
<td>245</td>
<td>0.96</td>
<td>26.61</td>
<td>37.26</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC+15%GGBS+SP</td>
<td>145</td>
<td>248</td>
<td>0.99</td>
<td>25.99</td>
<td>37.30</td>
</tr>
</tbody>
</table>

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**Fig. 5.42 Variation of Initial and Final Setting Times with Partial Replacement of OPC by Ground Granulated Blast Furnace Slag**
Fig. 5.43(a) Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Ordinary Portland Cement
Fig. 5.43(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Ordinary Portland Cement
Soundness Test Results

Soundness test results of the samples made with partial replacement of ordinary portland cement by GGBS are presented in the Table 5.23 and these values ranges between 0.70 mm to 0.99 mm. But this variation is very meager and less than the significant value, i.e., 10 mm and hence, the samples prepared without and with the combination of superplasticizer with partial replacement by GGBS are considered as sound.

Compressive Strength

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of GGBS without and with superplasticizer in ordinary portland cement along with the percentage change in the compressive strength are reported in Table 5.23 and the graphical representation of the variation in compressive strengths and percentage change in compressive strength are presented in Fig. 5.43(a) and Fig. 5.43(b) respectively.

From the Table 5.23 and Fig 5.43(a) it can be clearly evident that the compressive strength continued to increase as the age prolongs, indicating the pozzolanic action of GGBS. At the early ages i.e., 3 days the compressive strengths developed more slowly with the different dosage of GGBS replacement after which the rate of strength development increased sharply and are greater than that of control mix sample prepared without superplasticizer and with the superplasticizer.

The percentage change in the compressive strengths is represented in graphical form in Fig. 5.43(b). In the case of samples prepared in the presence of superplasticizer with 10% and 15% partial replacement by GGBS, the change observed is significant at almost all ages as the percentage changes are greater than 10%.

Similar results were reported by Wan et al. in the year 2004. As the percentage replacement of GGBS increases with and without superplasticizer, at all ages a considerable amount of increase in the compressive strengths are clearly observed which may be because of the formation of denser microstructure or lower porosity results from higher C-S-H at higher GGBS replacement percentage which is evident from SEM results also.
5.4.2.2 Durability Properties

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage weight loss when compared to the control mix samples are calculated. The effect of ground granulated blast furnace slag on partial replacement of ordinary portland cement are presented in Table 5.24 and in Fig. 5.44.

Table 5.24 Effect of Ground Granulated Blast Furnace Slag Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement +Admixture</th>
<th>Percentage Loss in Weight after 60 Days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100% OPC</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>95% OPC +5% GGBS</td>
<td>1.95</td>
</tr>
<tr>
<td>3</td>
<td>90% OPC +10% GGBS</td>
<td>1.90</td>
</tr>
<tr>
<td>4</td>
<td>85% OPC +15%GGBS</td>
<td>1.78</td>
</tr>
<tr>
<td>5</td>
<td>100% OPC +SP</td>
<td>1.70</td>
</tr>
<tr>
<td>6</td>
<td>95% OPC +5% GGBS +SP</td>
<td>1.66</td>
</tr>
<tr>
<td>7</td>
<td>90% OPC +10%GGBS +SP</td>
<td>1.60</td>
</tr>
<tr>
<td>8</td>
<td>85% OPC +15%GGBS +SP</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Fig. 5.44 Effect of GGBS Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss
From the Table 5.24 and Fig. 5.44 a weight loss of 1.95%, 1.90% and 1.78% against acid attack was exhibited by the mortar cubes prepared by partial replacement of ordinary portland cement by 5%, 10% and 15% respectively without superplasticizer. Mortar cubes prepared with the presence of superplasticizer and only ordinary portland cement showed a weight loss of 1.70% where as a weight loss of 1.66%, 1.60% and 1.58% are resulted with 5%, 10% and 15% replacement of ground granulated blast furnace slag with the presence of superplasticizer respectively against acid attack.

Against alkaline attack a weight loss of 1.38%, 1.35% and 1.15% was noticed for the mortar cubes prepared by partial replacement of portland slag cement by ground granulated blast furnace slag without superplasticizer. For mortar cubes with superplasticizer presence and only ordinary portland cement a weight loss of 1.22% was recognized where as a weight loss of 1.20%, 1.12% and 1.10% was identified with partial replacement by ground granulated blast furnace slag ash with superplasticizer presence.

A weight loss of 1.60%, 1.55% and 1.50% against sulphate attack was exhibited by the cubes prepared by partial replacement of ordinary portland cement by 5%, 10% and 15% respectively. For the cubes prepared by only ordinary portland cement with the addition of superplasticizer a weight loss of 1.42% was occurred, where as a loss of 1.36%, 1.34% and 1.32% appeared in the case of partial replacement with 5%, 10% and 15% replacement along with the addition of superplasticizer.

By observation it can be identified that weight reduction in the mortar cubes prepared with various combinations of ground granulated blast furnace slag exhibited reduction even up to 15% replacement, both without and with superplasticizer presence which implies that according to the investigation with the increase in the percentage of GGBS considerable amount of weight loss has occurred, this reduction may be continued up to an optimum dosage replacement.

The effect of GGBS on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.25 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.26 for ordinary portland cement. The variation of the compressive strength at 90 day are compared to acid, alkaline and sulphate test and are presented in Fig. 5.45 in the form of graphical representation.
Table 5.25  Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Ground Granulated Blast Furnace Slag without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>% Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>48.20</td>
<td>41.20</td>
<td>42.90</td>
<td>41.80</td>
<td>14.52</td>
<td>10.99</td>
<td>13.28</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% GGBS</td>
<td>50.99</td>
<td>44.30</td>
<td>45.20</td>
<td>44.60</td>
<td>13.12</td>
<td>11.35</td>
<td>12.54</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% GGBS</td>
<td>51.21</td>
<td>44.60</td>
<td>45.35</td>
<td>44.85</td>
<td>12.90</td>
<td>11.45</td>
<td>12.41</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% GGBS</td>
<td>51.78</td>
<td>44.91</td>
<td>45.47</td>
<td>45.80</td>
<td>13.26</td>
<td>12.18</td>
<td>12.94</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>50.24</td>
<td>43.50</td>
<td>44.60</td>
<td>44.10</td>
<td>13.42</td>
<td>11.23</td>
<td>12.22</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% GGBS+SP</td>
<td>52.20</td>
<td>45.10</td>
<td>46.10</td>
<td>45.80</td>
<td>13.60</td>
<td>11.68</td>
<td>12.26</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% GGBS+SP</td>
<td>52.90</td>
<td>45.70</td>
<td>46.35</td>
<td>45.85</td>
<td>13.61</td>
<td>12.38</td>
<td>13.32</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% GGBS+SP</td>
<td>54.03</td>
<td>46.85</td>
<td>48.05</td>
<td>47.02</td>
<td>13.28</td>
<td>11.06</td>
<td>12.98</td>
</tr>
</tbody>
</table>
Fig. 5.45 Comparison of Compressive Strength with Ordinary Portland Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Ground Granulated Blast Furnace Slag
Table 5.26  Permeability of Chloride in Ordinary Portland Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Ground Granulated Blast Furnace Slag

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement+ Admixture</th>
<th>I_0</th>
<th>I_30</th>
<th>I_60</th>
<th>I_90</th>
<th>I_120</th>
<th>I_150</th>
<th>I_180</th>
<th>I_210</th>
<th>I_240</th>
<th>I_270</th>
<th>I_300</th>
<th>I_330</th>
<th>I_360</th>
<th>I_{CUMULATIVE} in mA</th>
<th>I_{AVERAGE} in Coulombs</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td></td>
<td>2.30</td>
<td>2070</td>
<td>MODERATE</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5%GGBS</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td></td>
<td>1.99</td>
<td>1791</td>
<td>LOW</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10%GGBS</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>10</td>
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<td>12</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>1.82</td>
<td>1638</td>
<td>LOW</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15%GGBS</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<td>7</td>
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<td>11</td>
<td></td>
<td>1.05</td>
<td>945</td>
<td>VERY LOW</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>17</td>
<td>19</td>
<td></td>
<td>2.73</td>
<td>2457</td>
<td>MODERATE</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5%GGBS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td></td>
<td>1.38</td>
<td>1242</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10%GGBS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>16</td>
<td></td>
<td>1.64</td>
<td>1476</td>
<td>LOW</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15%GGBS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.45</td>
<td>405</td>
<td>VERY LOW</td>
</tr>
</tbody>
</table>
The compressive strength values after 90 days and after acid, alkaline, sulphate test and the percentage loss in the compressive strengths are presented in the Table 5.25 and Fig. 5.45. As already discussed more percentage loss means less resistance is offered by the mortar cubes to that particular attack.

Based on the experimental results presented in the Table 5.25 and Fig 5.45 the mortar cubes prepared by ordinary portland cement showed a percentage loss of 14.52, 10.99 and 13.28 for acid, alkaline and sulphate resistance attack tests respectively, which depicts that the mortar cubes showed greater resistance to alkaline than sulphate than acid attacks. Similar is the trend followed by the mortar cubes prepared by other combinations of ordinary portland cement by GGBS.

With the addition of the GGBS as partial replacement there was a slight loss in the compressive strength is appeared which in turn implies that there was a slight improvement in the resistance levels offered against acid, alkaline and sulphate attacks.

The rapid chloride permeability test results presented in Table 5.26 depicts that the control mixes with and without superplasticizer shows moderate resistance to chloride permeability, whereas the mortar cubes prepared by 5%, 10% GGBS replacement both with and without superplasticizer shows low permeability of chloride ions and with the further increase in the dosage of GGBS to 15% in both the cases very low permeability i.e., highest chloride ion penetration resistance is represented. Cheng et al. (2005) also studied the influence of GGBS on chloride permeability by RCPT and concluded that with the increase in the dosage of GGBS represented highest chloride ion penetration resistance which is identical to the results experimented in Table 5.26.

Enhancement in the durability properties may be due to denser microstructure or lower porosity resulted from higher C-S-H content that has occurred due to higher GGBS replacement percentage.

5.4.2.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for ordinary portland cement and ordinary portland cement with 15% GGBS without and with superplasticizer are presented in Fig. 5.46 and Fig. 5.47. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of ordinary portland cement with 15% replacement by GGBS without and with superplasticizer are presented in Fig. 5.48.
Fig. 5.46 Results of SEM and EDS - Ordinary Portland Cement + Ground Granulated Blast Furnace Slag

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>56.98</td>
<td>76.03</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.63</td>
<td>0.55</td>
</tr>
<tr>
<td>Si K</td>
<td>13.26</td>
<td>10.08</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>K K</td>
<td>2.94</td>
<td>1.60</td>
</tr>
<tr>
<td>Ca K</td>
<td>16.75</td>
<td>8.92</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.89</td>
<td>0.40</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.07</td>
<td>0.41</td>
</tr>
<tr>
<td>Br L</td>
<td>7.47</td>
<td>2.00</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5.47 Results of SEM and EDS - Ordinary Portland Cement + GGBS+SP

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>37.08</td>
<td>59.29</td>
</tr>
<tr>
<td>Na K</td>
<td>1.69</td>
<td>1.88</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.80</td>
<td>0.84</td>
</tr>
<tr>
<td>Al K</td>
<td>4.79</td>
<td>4.55</td>
</tr>
<tr>
<td>Si K</td>
<td>13.47</td>
<td>12.26</td>
</tr>
<tr>
<td>P K</td>
<td>0.09</td>
<td>0.07</td>
</tr>
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<td>Cl K</td>
<td>0.74</td>
<td>0.53</td>
</tr>
<tr>
<td>K K</td>
<td>0.54</td>
<td>0.35</td>
</tr>
<tr>
<td>Ca K</td>
<td>25.05</td>
<td>15.99</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Cr K</td>
<td>0.70</td>
<td>0.35</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>Fe K</td>
<td>5.11</td>
<td>2.34</td>
</tr>
<tr>
<td>Pd L</td>
<td>1.61</td>
<td>0.39</td>
</tr>
<tr>
<td>Au M</td>
<td>8.13</td>
<td>1.06</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5.48  XRD Results for Ordinary Portland Cement with Partial Replacement by GGBS
The micrograph presented in Fig. 5.46 illustrates that the ordinary portland cement mortar cubes prepared by partial replacement by GGBS particles without superplasticizer are present in the form of interweaving bunches with regular aggregation due to flocculation and also a few needle shape ettringite existed in these specimens and C-S-H gel is formed as reaction product, which is same as the SEM results presented by Daube and Bakker.

The micrograph Fig. 5.47 revealed for OPC cement mortar particles with GGBS and SP shows a small aggregated arrangement with plates and laths grouping structure with loose dense nature of arrangement of above particles.

From the results presented in Fig. 5.46 and Fig. 5.47 it is clearly identified that the elements present in major amounts are oxygen, calcium, silica and aluminium with a very few amounts of some other elements. From the XRD results presented in Table 5.22 monoclinic structure is exhibited by the samples prepared from mortar cubes of ordinary portland cement partial replacement by GGBS both without and with superplasticizer with possible compound as calcium silicate in both the cases and 2θ angle is around 26⁰ which are identified by matching the results obtained with standard JCPDS data with the peaks present in Fig. 48.

When supplementary cementing materials like GGBS are used in mortar they not only reduce the porosity but also the pores become finer and the change in the mineralogy of cement hydrates leads to the formation of pozzolanic reaction products such as low density C-S-H gel, calcium silicate which increases the setting times and strength gain characteristics and durability properties, which can be identified from the various results presented in SEM and XRD results also.

5.4.3 EFFECT OF MICRO SILICA ON DIFFERENT PROPERTIES OF ORDINARY PORTLAND CEMENT

5.4.3.1 Mechanical Properties

Test results of initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths of cement mortar cubes with 5%, 10% and 15% partial replacement of ordinary portland cement by microsilica without and with superplasticizer are presented in the Table 5.27 and the variations in the setting times and variations in the compressive strength and percentage change in compressive strength are exhibited in the graphical representation as Fig. 5.49, Fig. 5.50(a) and Fig. 5.50(b) and respectively.
Table 5.27  Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Microsilica without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>123</td>
<td>218</td>
<td>0.77</td>
<td>23.60</td>
<td>33.90</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% MS</td>
<td>128</td>
<td>228</td>
<td>1.00</td>
<td>24.49</td>
<td>39.49</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% MS</td>
<td>132</td>
<td>235</td>
<td>1.05</td>
<td>26.57</td>
<td>39.75</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% MS</td>
<td>143</td>
<td>240</td>
<td>1.08</td>
<td>24.02</td>
<td>34.25</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>135</td>
<td>240</td>
<td>0.88</td>
<td>24.90</td>
<td>35.43</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% MS+SP</td>
<td>148</td>
<td>245</td>
<td>1.00</td>
<td>26.80</td>
<td>39.72</td>
</tr>
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<td>90%OPC +10% MS+SP</td>
<td>162</td>
<td>252</td>
<td>1.16</td>
<td>28.24</td>
<td>39.80</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% MS+SP</td>
<td>180</td>
<td>260</td>
<td>1.57</td>
<td>26.04</td>
<td>37.45</td>
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</table>
Various Combinations of Ordinary Portland Cement with Microsilica

Fig. 5.49 Variation of Initial and Final Setting Times with the Partial Replacement of Ordinary Portland Cement by Microsilica
Various Combinations of Ordinary Portland Slag Cement with Microsilica

Fig. 5.50(a) Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica without and with Superplasticizer in Ordinary Portland Cement
Fig. 5.50(b)  Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica without and with Superplasticizer in Ordinary Portland Cement
Initial and Final Setting Times

From the Table 5.27 and Fig. 5.49 it is observed that both the initial and final setting times got retarded by partial replacement by microsilica in the ordinary portland cement.

The initial setting times of samples prepared by 5%, 10% and 15% replacement of ordinary portland cement by microsilica without the presence of superplasticizer show an increase of 5, 9 and 20 minutes respectively. The change in these initial setting times is considered as insignificant as these values are slightly more than that of the ordinary portland cement. Similarly the final setting times are delayed by 10, 17 and 22 minutes more than that of the ordinary portland cement samples respectively and these changes are also considered as insignificant. The delays caused in both setting times are increased from 4% to 16% with the increase in the percentage increase in the replacement of microsilica.

The initial setting times for the mortar cubes prepared by partial replacement of cement by microsilica along with superplasticizer showed a delay of 25, 39 and 57 minutes. The changes that occurred in the samples prepared by 5% replacement of microsilica along with superplasticizer is considered to be insignificant whereas the change is significant in the case of 10% and 15% replacement in the presence of superplasticizer. The changes in the final setting times are delayed by 27, 34 and 42 minutes respectively by 5%, 10% and 15% replacement of ordinary portland cement by microsilica along with superplasticizer. Here the change in the case of 5% replacement is considered as insignificant whereas in the case of 10% and 15% the change is significant as they are greater than 30 minutes. These can be identified clearly in Fig. 5.49.

When 15% microsilica is added with superplasticizer, both the initial and final setting times are delayed by approximately one hour when compared to the control mix prepared by ordinary portland cement only. These results are almost same as the conclusions drawn by Lohtia and Joshi (1996). Alshamsi et al. (1993) also reported that addition of microsilica lengthened the setting time of pastes. The delay in the setting times may be because, the addition of microsilica replaces part of OPC reducing the early stiffening potential by the pozzolanic action.

Soundness Test Results

Soundness test results of the samples made with partial replacement of ordinary portland cement by microsilica are presented in the Table 5.27. These values range between 0.77 mm to 1.57 mm. But these variations are negligible than the significant value,
i.e., 10 mm and hence, there is no appreciable change in the volume of the samples. So the samples prepared by different combinations are considered as sound samples.

**Compressive Strength**

Variation of compressive strength of cement mortar cubes at different ages made with partial replacement of microsilica without and with superplasticizer in ordinary portland cement along with the percentage change in the compressive strengths are reported in Table 5.28 and the graphical representation of the variations in compressive strengths and percentage change in the compressive strength are also presented in Fig. 5.50(a) and Fig. 5.50(b) respectively.

From the tabulated results it can be clearly identified that the compressive strength increases with the increase in microsilica replacement up to 10% both in the case of mortar cubes prepared with and without the presence of superplasticizer and then it started diminishing with the further increase in the percentage replacement of microsilica to 15% at all the ages considered, though the increase is slightly appeared at the early ages.

From Table 5.28 and Fig. 5.50(b) it is clear that the percentage change in the compressive strength varies from 2% to even 20% at some ages showing a wide range of variations. In the case of mortar cubes prepared by 10% replacement by microsilica without the presence of superplasticizer a significant change is appearing whereas with the presence of superplasticizer the percentage change in the compressive strength can be considered as significant change for 5%, 10% and 15% replacement levels at almost all ages. This was due to the reaction of microsilica with calcium hydroxide formed during the hydration of cement which caused the formation of more amount of calcium silicate hydrate i.e., C-S-H gel. Similar types of conclusions were drawn by Elsayed (2011) from his studies conducted on microsilica.

**5.4.3.2 Durability Properties**

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage weight loss when compared to the control mix samples are calculated. The effect of microsilica on partial replacement of ordinary portland cement are presented in Table 5.28 and in Fig. 5.51.
Table 5.28  Effect of Microsilica Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>Percentage Loss in Weight after 60 Days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100% OPC</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>95% OPC + 5% MS</td>
<td>1.90</td>
</tr>
<tr>
<td>3</td>
<td>90% OPC + 10% MS</td>
<td>1.88</td>
</tr>
<tr>
<td>4</td>
<td>85% OPC + 15% MS</td>
<td>1.89</td>
</tr>
<tr>
<td>5</td>
<td>100% OPC + SP</td>
<td>1.70</td>
</tr>
<tr>
<td>6</td>
<td>95% OPC + 5% MS + SP</td>
<td>1.68</td>
</tr>
<tr>
<td>7</td>
<td>90% OPC + 10% MS + SP</td>
<td>1.64</td>
</tr>
<tr>
<td>8</td>
<td>85% OPC + 15% MS + SP</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Fig. 5.51  Effect of Microsilica Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

The results presented in Table 5.28 and Fig. 5.51 depicts that the percentage loss in weight started declining with the increase in dosage replacement of ordinary portland cement by microsilica up to 10% and then the percentage weight loss is slightly increased at 15% replacement in the samples tested, which also reveals that more amount of percentage weight loss has occurred due to acid attack followed by sulphate and then by alkaline attack.
A difference in the percentage weight loss of 0.15%, 0.17% and 0.16% is observed in the case of mortar cubes prepared with 5%, 10% and 15% partial replacement by microsilica respectively without the presence of superplasticizer for acid attack. In the similar manner a difference of 0.35%, 0.37%, 0.41% and 0.39% with the presence of superplasticizer and with partial replacement by 5%, 10% and 15% microsilica along with superplasticizer respectively when compared to mortar cubes prepared by only ordinary portland cement.

A difference of 0.06% followed by 0.12% and 0.1% occurred with the presence of superplasticizer, which changed to 0.18%, 0.22%, 0.24% and 0.20% with the addition of superplasticizer to ordinary portland cement and with partial replacement of microsilica for alkaline attack.

For sulphate attacks in the mortar cubes prepared with partial replacement of microsilica without superplasticizer, a difference in the percentage weight loss of 0.01%, 0.05% and 0.02% is exhibited. With the addition of the superplasticizer a weight loss with a difference of 0.23%, 0.29%, 0.35% and 0.33% occurred when compared to the mortar cubes of ordinary portland cement.

From the above results it is recognized that weight loss is more in the case of acid test, than sulphate test than alkaline test. So, more resistance is exhibited against alkaline test followed by sulphate test and then finally by acid test. This percentage loss in weight decreased with the addition of microsilica up to 10% replacement which is shown by increasing difference in the previous discussion and then presented a slight increase in the weight loss by 15% replacement. This further implies that optimum dosage replacement of microsilica is 10% out of 5%, 10% and 15%.

The effect of partial replacement of microsilica on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.29 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.30 for ordinary portland cement. The variation of the compressive strength values at 90 day are compared to acid, alkaline and sulphate test and are presented in Fig. 5.52 in the form of bar chart. As already presented in the previous discussions, more percentage loss in compressive strength indicates that less resistance is offered by the mortar cubes to that particular attack.
Table 5.29  Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Microsilica without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>48.20</td>
<td>41.20</td>
<td>42.90</td>
<td>41.80</td>
<td>14.52</td>
<td>10.99</td>
<td>13.28</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5%MS</td>
<td>51.86</td>
<td>45.70</td>
<td>46.40</td>
<td>45.80</td>
<td>11.88</td>
<td>10.54</td>
<td>11.68</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10%MS</td>
<td>53.46</td>
<td>46.80</td>
<td>47.30</td>
<td>47.05</td>
<td>12.45</td>
<td>11.52</td>
<td>12.00</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15%MS</td>
<td>49.92</td>
<td>43.50</td>
<td>44.74</td>
<td>44.47</td>
<td>12.86</td>
<td>10.38</td>
<td>10.92</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>50.24</td>
<td>43.50</td>
<td>44.60</td>
<td>44.10</td>
<td>13.42</td>
<td>11.23</td>
<td>12.22</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5%MS+SP</td>
<td>53.46</td>
<td>47.20</td>
<td>47.70</td>
<td>47.60</td>
<td>11.70</td>
<td>10.78</td>
<td>10.96</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10%MS+SP</td>
<td>56.60</td>
<td>49.50</td>
<td>49.95</td>
<td>49.60</td>
<td>12.54</td>
<td>11.74</td>
<td>12.36</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15%MS+SP</td>
<td>52.96</td>
<td>46.88</td>
<td>47.35</td>
<td>47.20</td>
<td>11.48</td>
<td>10.59</td>
<td>10.88</td>
</tr>
</tbody>
</table>
Fig. 5.52  Comparison of Compressive strength with Ordinary Portland Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Microsilica
Table 5.30 Permeability of Chloride in Ordinary Portland Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Microsilica

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement+ Admixture</th>
<th>$I_0$</th>
<th>$I_{30}$</th>
<th>$I_{60}$</th>
<th>$I_{90}$</th>
<th>$I_{120}$</th>
<th>$I_{150}$</th>
<th>$I_{180}$</th>
<th>$I_{210}$</th>
<th>$I_{240}$</th>
<th>$I_{270}$</th>
<th>$I_{300}$</th>
<th>$I_{330}$</th>
<th>$I_{360}$</th>
<th>$I_{CUMULATIVE} \text{ in mA}$</th>
<th>$I_{AVERAGE} \text{ in Coulombs}$</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>2.30</td>
<td>2070</td>
<td>MODERATE</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% MS</td>
<td>8</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>17</td>
<td>20</td>
<td>19</td>
<td>17</td>
<td>18</td>
<td>3.26</td>
<td>2934</td>
<td>MODERATE</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% MS</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>14</td>
<td>16</td>
<td>1.44</td>
<td>1296</td>
<td>LOW</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% MS</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>0.96</td>
<td>864</td>
<td>VERY LOW</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>17</td>
<td>19</td>
<td>19</td>
<td>2.73</td>
<td>2457</td>
<td>MODERATE</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% MS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>1.23</td>
<td>1107</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% MS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>0.58</td>
<td>522</td>
<td>VERY LOW</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% MS+SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.24</td>
<td>216</td>
<td>VERY LOW</td>
</tr>
</tbody>
</table>
From the Table 5.29 the loss in the compressive strength values for the mortar cubes prepared by ordinary portland cement are 14.52%, 10.99% and 13.28% after acid, alkaline and sulphate tests respectively. Hence the resistance offered is of the order alkaline greater than sulphate greater than acid attack. The remaining all combinations i.e. ordinary portland cement with partial replacement by 5%, 10% and 15% microsilica both with and without the addition of superplasticizer followed the same trend of resistance respectively. But a slight increase in the percentage loss in compressive strengths occurred when the replacement of microsilica increased to 15% both without and with the presence of superplasticizer. So, 10% replacement can be considered as optimum level of replacement among 5%, 10% and 15% replacements. So improvement in resisting the acid, alkaline and sulphate tests can be achieved by replacing cement by microsilica up to certain scale of replacement which can be evident even in Fig. 5.52 also. Almost all the combinations, at different replacement levels by weight of OPC plays a key role in resisting sulphate attack indicating no signs of spalling same as the studies conducted by Wee et al. (2000).

Mortar cylindrical specimens prepared by ordinary portland cement alone and in combination with superplasticizer alone and with 5% replacement by microsilica are exhibiting moderate penetrability to chloride ions when tested with standard RCPT. With the increments in the percentage replacement levels by microsilica both with out and with the presence of superplasticizer showed increased resistance to chloride attack which are indicated by changes from moderate to low and then low to very low penetrability as indicated in the Table 5.30 based on the charges passing through the cylindrical test specimens tested using RCPT apparatus.

Addition of microsilica to mortar improves the durability through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to various attacks like acid, alkaline, sulphate and chloride attacks.

5.4.3.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for ordinary portland cement with 15% replacement by microsilica without and with superplasticizer are presented in Fig. 5.53 and Fig. 5.54 respectively. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of portland slag cement with partial replacement by microsilica without and with superplasticizer are presented in Fig. 5.55.
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>54.47</td>
<td>71.36</td>
</tr>
<tr>
<td>Na K</td>
<td>0.34</td>
<td>0.31</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.73</td>
<td>0.63</td>
</tr>
<tr>
<td>Al K</td>
<td>4.39</td>
<td>3.41</td>
</tr>
<tr>
<td>Si K</td>
<td>15.38</td>
<td>11.47</td>
</tr>
<tr>
<td>Cl K</td>
<td>1.11</td>
<td>0.66</td>
</tr>
<tr>
<td>K K</td>
<td>3.61</td>
<td>1.93</td>
</tr>
<tr>
<td>Ca K</td>
<td>18.47</td>
<td>9.66</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Mn K</td>
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<td>0.02</td>
</tr>
<tr>
<td>Fe K</td>
<td>1.41</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.53 Results of SEM and EDS - Ordinary Portland Cement + Microsilica
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
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<td>67.35</td>
</tr>
<tr>
<td>Na K</td>
<td>0.56</td>
<td>0.59</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Al K</td>
<td>1.07</td>
<td>0.96</td>
</tr>
<tr>
<td>Si K</td>
<td>14.91</td>
<td>12.95</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.47</td>
<td>0.32</td>
</tr>
<tr>
<td>K K</td>
<td>0.57</td>
<td>0.36</td>
</tr>
<tr>
<td>Ca K</td>
<td>20.18</td>
<td>12.29</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Cr K</td>
<td>1.00</td>
<td>0.47</td>
</tr>
<tr>
<td>Fe K</td>
<td>6.75</td>
<td>2.95</td>
</tr>
<tr>
<td>Pd L</td>
<td>1.42</td>
<td>0.33</td>
</tr>
<tr>
<td>W M</td>
<td>1.53</td>
<td>0.20</td>
</tr>
<tr>
<td>Au M</td>
<td>7.00</td>
<td>0.87</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.54 Results of SEM and EDS - Ordinary Portland Cement + Microsilica+ Superplasticizer
Fig. 5.55 XRD Results for Ordinary Portland Cement with Partial Replacement by Microsilica
The micrograph referred in Fig. 5.53 reveals that when the partial replacement of portland slag cement with microsilica is done the cement mortar particles presents a partly discernable particle system with transassemblages with regular connectors and formation of interspaces which shows flakey arrangements with transassemblage system when superplasticizer is also present in the mortar, which is as presented in Fig. 5.54.

From the results presented in Fig. 5.53 and Fig. 5.54 the elements which are present in maximum quantities are identified as oxygen, calcium, silica, aluminum and iron and the presence of few more elements follows in small quantities.

From the XRD results presented in Table 5.22, anorthic structure is exhibited by the samples prepared from mortar cubes of ordinary portland cement with partial replacement by microsilica without superplasticizer and with superplasticizer with possible compounds as calcium hydroxide (hematite) and calcium aluminium silicate respectively and in both the cases 2θ angle is around 26° which are identified by matching the results obtained with standard JCPDS data with the peaks present in Fig. 5.55.

Based on the various investigations presented above it can be concluded that mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. Mechanism behind is not only connected to chemical formation of C-S-H at interface, but also because of microstructure modification which can be evident from SEM and XRD analysis which shows the change of monoclinic structure to anorthic by the formation of compounds like hematite, in addition to forming strength contributing cementitious products which in other words can be termed as pozzolanic reaction.

5.4.4 EFFECT OF RICE HUSK ASH ON DIFFERENT PROPERTIES OF ORDINARY PORTLAND CEMENT

5.4.4.1 Mechanical Properties

Mechanical properties such as initial and final setting times, soundness, compressive strengths and percentage change in compressive strengths at different ages are presented in Table 5.31 and variations in setting times, compressive strengths and percentage change in compressive strengths are presented in graphical form in Fig. 5.56, Fig. 5.57(a) and Fig. 5.57(b) respectively.
Table 5.31 Mechanical Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Soundness (mm)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>123</td>
<td>218</td>
<td>0.77</td>
<td>23.60</td>
<td>33.90</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% RHA</td>
<td>120</td>
<td>210</td>
<td>0.80</td>
<td>23.97</td>
<td>34.84</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% RHA</td>
<td>118</td>
<td>208</td>
<td>0.90</td>
<td>25.56</td>
<td>37.16</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% RHA</td>
<td>115</td>
<td>204</td>
<td>0.92</td>
<td>24.46</td>
<td>34.32</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>135</td>
<td>240</td>
<td>0.88</td>
<td>24.90</td>
<td>35.43</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% RHA +SP</td>
<td>115</td>
<td>225</td>
<td>0.60</td>
<td>25.09</td>
<td>35.58</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% RHA +SP</td>
<td>110</td>
<td>218</td>
<td>0.76</td>
<td>26.99</td>
<td>37.48</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% RHA +SP</td>
<td>105</td>
<td>215</td>
<td>0.83</td>
<td>25.94</td>
<td>37.40</td>
</tr>
</tbody>
</table>
Fig. 5.56 Variation of Initial and Final Setting Times with Partial Replacement of Ordinary Portland Cement by Rice Husk Ash
Fig. 5.57(a)  Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Ordinary Portland Cement
Fig. 5.57(b) Variation of Percentage Change in Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Ordinary Portland Cement
The initial setting times diminished by an amount of 03, 05 and 13 minutes by partial replacement of ordinary portland cement by 5%, 10% and 15% rice husk ash respectively without superplasticizer. Whereas a decrease of 13, 18 and 23 minutes is observed in the case of samples prepared by partial replacement by 5%, 10%, 15% with rice husk ash with the presence of superplasticizer. The change is considered as insignificant in all the combinations as it is not exceeding 30 minutes.

A decrease in the final setting times by an amount of 18, 10 and 14 minutes in samples without superplasticizer and very slight changes with the presence of superplasticizer is clearly noticed, with 5%, 10% and 15% replacement by rice husk ash respectively which are also considered as insignificant changes.

So, early setting times are observed with partial replacement of ordinary portland cement with rice husk ash than that of control mix samples. Sensale et al. (2008) investigated the influence of partial replacement of ordinary portland cement by rice husk ash on setting times of cement paste and concluded that setting times decreased with increase in the rice husk ash content. These are same as the observations done in the present investigation also.

**Soundness Test Results**

Soundness test results of the samples made with partial replacement of ordinary portland cement by rice husk ash are presented in the Tables 5.31, and these values ranges between 0.77 mm to 0.92 mm. But these variations are considered as meager when compared to the significant value, i.e., 10 mm and hence, there is no appreciable change in the volume of the samples is observed both in the case of the samples prepared without and with the combination of superplasticizer and all the samples are considered to be sound.

**Compressive Strength**

From Table 5.31 and Fig. 5.57(a) it can be observed that inclusion of rice husk ash as partial replacement of ordinary portland cement enhances the compressive strength up to a certain replacement dosage then with the further increase in the rice husk ash percentage replacement the compressive strength diminishes. This type of increase is observed up to 10% replacement and then it decreased with 15% replacement at all ages. So, it can be concluded that an optimum dosage of percentage
replacement lies between 10% and 15%. Significant improvement in the strengths can be identified in 10% and 15% replacement level along with the presence of superplasticizer. But more significant changes can be identified at all ages for 10% replacement by RHA with the presence of superplasticizer. Similar suggestions were given by Zhang et al. (1996) from their investigations in which they have suggested 10% RHA replacement exhibited upper strength than control OPC at all ages.

5.4.4.2 Durability Properties

Before conducting the compressive strength tests on mortar cubes after immersion in different solutions prepared for acid, alkaline and sulphate tests for finding out the durability properties, the weights of the mortar cubes are noted and the percentage weight loss when compared to the control mix samples are calculated. The effect of rice husk ash on partial replacement of ordinary portland cement are presented in Table 5.32 and in Fig. 5.58.

Table 5.32 Effect of Rice Husk Ash Replacement on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement + Admixture</th>
<th>Percentage Loss in Weight after 60 Days Immersion in Different Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Acid Solution</td>
</tr>
<tr>
<td>1</td>
<td>100% OPC</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>95% OPC +5% RHA</td>
<td>1.98</td>
</tr>
<tr>
<td>3</td>
<td>90% OPC +10% RHA</td>
<td>1.90</td>
</tr>
<tr>
<td>4</td>
<td>85% OPC +15% RHA</td>
<td>1.92</td>
</tr>
<tr>
<td>5</td>
<td>100% OPC +SP</td>
<td>1.70</td>
</tr>
<tr>
<td>6</td>
<td>95% OPC +5% RHA+SP</td>
<td>1.76</td>
</tr>
<tr>
<td>7</td>
<td>90% OPC +10% RHA+SP</td>
<td>1.70</td>
</tr>
<tr>
<td>8</td>
<td>85% OPC +15% RHA+SP</td>
<td>1.74</td>
</tr>
</tbody>
</table>
Various Combinations of Ordinary Portland Cement with Rice Husk Ash

Fig. 5.58 Effect of Rice Husk Ash on Ordinary Portland Cement without and with Superplasticizer on Percentage Weight Loss

From the Table 5.32 and Fig. 5.58 a weight loss of 1.98%, 1.90% and 1.92% against acid attack was exhibited by the mortar cubes prepared by partial replacement of ordinary portland cement by 5%, 10% and 15% respectively without superplasticizer. Mortar cubes prepared with the presence of superplasticizer and only ordinary portland cement showed a weight loss of 1.70% where as a weight loss of 1.76%, 1.70% and 1.74% are resulted with 5%, 10% and 15% replacement of rice husk ash with the presence of superplasticizer respectively against acid attack.

Against alkaline attack a weight loss of 1.36%, 1.33% and 1.34% was noticed for the mortar cubes prepared by partial replacement of ordinary portland cement by rice husk ash without superplasticizer. For mortar cubes with superplasticizer presence and only ordinary portland cement a weight loss of 1.22% was recognized where as a weight loss of 1.20%, 1.18% and 1.19% was identified with partial replacement by rice husk ash with superplasticizer presence.
A weight loss of 1.56%, 1.52% and 1.54% against sulphate attack was exhibited by the cubes prepared by partial replacement of ordinary portland cement by 5%, 10% and 15% respectively. For the cubes prepared by only ordinary portland cement with the addition of superplasticizer a weight loss of 1.42% was occurred, where as a loss of 1.40%, 1.38% and 1.39% appeared in the case of partial replacement with 5%, 10% and 15% replacement along with the addition of superplasticizer.

By observation it can be identified that weight reduction in the mortar cubes prepared with various combinations of rice husk ash exhibited reduction up to 10% replacement only, both without and with superplasticizer presence which implies that according to the investigations 10% replacement level can be considered as optimum among 5%, 10% and 15% replacement levels.

The effect of partial replacement of rice husk ash on different durability tests such as acid test, alkaline test and sulphate test along with percentage loss in compressive strength are presented in Table 5.33 and Fig. 5.59 and test results of chloride permeability through rapid chloride permeability test are presented in Table 5.34 for ordinary portland cement. As already presented in the previous discussions, more percentage loss in compressive strength indicates that less resistance is offered by the mortar cubes to that particular attack.

From the durability test results presented in Table 5.33 and Fig. 5.59 it can be clearly noted that mortar cubes prepared by ordinary portland cement and ordinary portland cement by 5%, 10%, 15% replacement by rice husk ash without and with superplasticizer exhibited resistance of the order alkaline followed by sulphate followed by acid attacks. The resistance offered accelerated with the increase in the RHA levels up to 10% replacement and it decreased with the further increase to 15% replacement levels both without and with superplasticizer. This may be due to the presence of irregular shaped particles with porous cellular surface which can be identified in the results presented in SEM analysis.
Table 5.33 Durability Properties of Cement Mortar Cubes at Different Ages Made with Partial Replacement of Rice Husk Ash without and with Superplasticizer in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (Mpa)</th>
<th>Alkaline Test (Mpa)</th>
<th>Sulphate Test (Mpa)</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>48.20</td>
<td>41.20</td>
<td>42.90</td>
<td>41.80</td>
<td>14.52</td>
<td>10.99</td>
<td>13.28</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% RHA</td>
<td>51.54</td>
<td>45.20</td>
<td>45.70</td>
<td>45.30</td>
<td>12.30</td>
<td>11.34</td>
<td>12.10</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% RHA</td>
<td>52.35</td>
<td>45.80</td>
<td>46.85</td>
<td>46.50</td>
<td>12.51</td>
<td>10.50</td>
<td>11.18</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% RHA</td>
<td>50.12</td>
<td>44.53</td>
<td>45.10</td>
<td>44.97</td>
<td>11.15</td>
<td>10.01</td>
<td>10.28</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>50.24</td>
<td>43.50</td>
<td>44.60</td>
<td>44.10</td>
<td>13.42</td>
<td>11.23</td>
<td>12.22</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% RHA +SP</td>
<td>51.54</td>
<td>44.90</td>
<td>45.60</td>
<td>45.20</td>
<td>12.88</td>
<td>11.52</td>
<td>12.30</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% RHA +SP</td>
<td>54.02</td>
<td>47.05</td>
<td>47.60</td>
<td>47.45</td>
<td>12.90</td>
<td>11.88</td>
<td>12.16</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% RHA +SP</td>
<td>53.28</td>
<td>46.40</td>
<td>47.05</td>
<td>46.95</td>
<td>12.90</td>
<td>11.70</td>
<td>11.88</td>
</tr>
</tbody>
</table>
Various Combinations of Ordinary Portland Cement with Rice Husk Ash

Fig. 5.59 Comparison of Compressive Strength with Ordinary Portland Cement at 90 Day to Acid, Alkaline and Sulphate Tests with Different Dosages of Rice Husk Ash
Table 5.34  Permeability of Chloride in Ordinary Portland Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for Different Dosages of Rice Husk Ash

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement+Admixture</th>
<th>$I_0$</th>
<th>$I_{30}$</th>
<th>$I_{60}$</th>
<th>$I_{120}$</th>
<th>$I_{180}$</th>
<th>$I_{240}$</th>
<th>$I_{300}$</th>
<th>$I_{360}$</th>
<th>$I_{CUMULATIVE}$</th>
<th>$I_{AVERAGE}$</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%OPC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>2.30</td>
</tr>
<tr>
<td>2</td>
<td>95%OPC +5% RHA</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>14</td>
<td>1.94</td>
</tr>
<tr>
<td>3</td>
<td>90%OPC +10% RHA</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>2.11</td>
</tr>
<tr>
<td>4</td>
<td>85%OPC +15% RHA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>0.64</td>
</tr>
<tr>
<td>5</td>
<td>100%OPC +SP</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>2.73</td>
</tr>
<tr>
<td>6</td>
<td>95%OPC +5% RHA +SP</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>1.44</td>
</tr>
<tr>
<td>7</td>
<td>90%OPC +10% RHA +SP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>1.73</td>
</tr>
<tr>
<td>8</td>
<td>85%OPC +15% RHA +SP</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>1.25</td>
</tr>
</tbody>
</table>
The rapid chloride permeability test results present in Table 5.34 indicate that the control mix samples i.e. cubes of ordinary portland cement and ordinary portland cement with superplasticizer are exhibiting moderate permeability of chloride ions where as with the increase in percentage replacement by rice husk ash the penetrability is decreased to the low ratings of penetration which implies that resistance levels are increasing with increase in dosage of rice husk ash partial replacement. It was observed that replacement of rice husk ash drastically reduced coulomb values. As the replacement level increased, the chloride penetration decreased.

Ganesan et al. (2008), Chindaprasirt et al. (2008) and Ramazanianpour et al. (2009) has done similar studies and observed that rice husk ash drastically enhanced resistance to chloride penetration compared to control mixes and similar conclusions are drawn from the present investigation also.

5.4.4.3 SEM, EDS and XRD Results

The results of the SEM along with EDS for ordinary portland cement by partial replacement by rice husk ash without and with superplasticizer are presented in Fig. 5.60 and Fig. 5.61 respectively. The various elements along with percentage weight and atomic percent are also presented in the same figures. The XRD results of portland slag cement with partial replacement by rice husk ash without and with superplasticizer are presented in Fig. 5.62. XRD results of ordinary portland cement are presented in Table 5.22.

The micrograph for partial replacement of ordinary portland cement by rice husk ash is presented in Fig. 5.60 which shows sheets like structure and flaky arrangements of the particles. The micrograph illustrated in Fig. 5.61 for ordinary portland cement mortar particles replaced with rice husk ash with superplasticizer shows the formation of cement matrix assemblage with interweaving bunches due to flocculation and aggregation of cement mortar particles.
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>58.88</td>
<td>74.33</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Al K</td>
<td>0.29</td>
<td>0.22</td>
</tr>
<tr>
<td>Si K</td>
<td>23.17</td>
<td>16.66</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>K K</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Ca K</td>
<td>16.03</td>
<td>8.08</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.83</td>
<td>0.35</td>
</tr>
<tr>
<td>Mn K</td>
<td>0.19</td>
<td>0.07</td>
</tr>
<tr>
<td>Fe K</td>
<td>0.31</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100.00</td>
<td></td>
</tr>
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</table>

Fig. 5.60 Results of SEM and EDS – Ordinary Portland Cement + Rice Husk Ash

197
<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O K</td>
<td>66.18</td>
<td>80.87</td>
</tr>
<tr>
<td>Na K</td>
<td>0.40</td>
<td>0.34</td>
</tr>
<tr>
<td>Mg K</td>
<td>0.57</td>
<td>0.46</td>
</tr>
<tr>
<td>Al K</td>
<td>1.83</td>
<td>1.33</td>
</tr>
<tr>
<td>Si K</td>
<td>9.25</td>
<td>6.44</td>
</tr>
<tr>
<td>P K</td>
<td>0.14</td>
<td>0.09</td>
</tr>
<tr>
<td>Cl K</td>
<td>0.19</td>
<td>0.10</td>
</tr>
<tr>
<td>K K</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Ca K</td>
<td>20.62</td>
<td>10.06</td>
</tr>
<tr>
<td>Ti K</td>
<td>0.15</td>
<td>0.06</td>
</tr>
<tr>
<td>Mn K</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Fe K</td>
<td>0.55</td>
<td>0.19</td>
</tr>
<tr>
<td>Totals</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5.61 Results of SEM and EDS – Ordinary Portland Cement + Rice Husk Ash + Superplasticizer
Fig. 5.62 XRD Results for Ordinary Portland Cement with Partial Replacement by Rice Husk Ash
The hexagonal shaped CH crystals (Ca(OH)$_2$) with large crystalline particles and the foil honey comb structure of calcium silicate hydrate (C-S-H) are present in the micrograph. It is an indication of hydration reaction. The surface area of the RHA particles is not covered by hydration products. The pores are filled by C-S-H and other by products. The volume of C-S-H crystals are more dominant compared with Ca(OH)$_2$ crystals generally present in OPC hydrated products. Hence rice husk ash acts as a good pozzolanic material and can be blended with cement.

The various elements present in the mortar cubes are identified by presented in the SEM results in Fig. 5.60 and Fig. 5.61. The elements present in major quantities are oxygen, calcium, silica, aluminium and iron and small traces of some other elements.

From the XRD results presented in Table 5.22 and they show that the monoclinic structure is changed to orthorhombic with the inclusion of superplasticizer with replacement of ordinary portland cement by 15% rice husk ash by weight and the 20 angle is around 26° in both the cases, which are identified by comparing the results with standard JCPDS data.

From the various results discussed in the previous sections it can be understood that the decrease in the setting times, increase in the compressive strengths up to certain level of replacement and enhancement in the durability properties are occurring because of the partial replacement of OPC by rice husk ash are because of the changes in the structure and formation of various compounds and filling of the pore spaces with C-S-H which further accelerates the pozzolanic action which are matching with the results presented in SEM and XRD analysis.

5.5 COMPARISON OF DIFFERENT PROPERTIES OF CEMENT BY PARTIAL REPLACEMENT OF PORTLAND SLAG CEMENT AND ORDINARY PORTLAND CEMENT BY DIFFERENT ADMIXTURES

As in the present investigation two types of cements with four types of mineral admixtures and one chemical admixture as superplasticizer is used, the best combination has to be suggested. So, comparison is done between different combinations.

For finding the best combination in each and every admixture the various mechanical and durability properties of portland slag cement are compared to ordinary portland cement without and with the presence of superplasticizer, and are presented in the following sections.
5.5.1 VARIATIONS OF SETTING TIMES

The variations of setting times with portland slag cement and ordinary portland cement with fly ash, ground granulated blast furnace slag, microsilica and rice husk ash without and with the presence of superplasticizer are presented in the Fig. 5.64 to Fig. 5.67 respectively.

![Graph showing variations of setting times with different replacement levels of fly ash for PSC and OPC samples.](image)

**Fig. 5.63 Variation of Setting Times in PSC and OPC Samples with Partial Replacement by Fly Ash**

From the Fig. 5.63 it is clear that the initial and final setting times with partial replacement by fly ash for both portland slag cement and ordinary portland cement followed similar trends. The setting times are getting delayed with the increase in the dosage of fly ash and the higher amount of delay in the setting times is observed in the case of portland slag cement with fly ash with superplasticizer.
Fig. 5.64 Variation of Setting Times in PSC and OPC Samples with Partial Replacement by Ground Granulated Blast Furnace Slag

From Fig. 5.64 the initial setting times gradually takes longer time with the GGBS replacement though this delay was found less in the case of PSC and OPC with GGBS along with superplasticizer.

In the case of final setting times with the partial replacement by GGBS both in PSC and OPC there appeared a delay in the setting times where as with the addition of superplasticizer there also appeared a similar trend and the combination of PSC with GGBS along with superplasticizer is taking longer times both in the case of initial and final setting times.
Fig. 5.65 Variation of Setting Times in PSC and OPC Samples with Partial Replacement by Microsilica

From the Fig. 5.65 both the initial and final setting times showed a delay in the setting times with the replacement by microsilica. The combination of OPC with microsilica along with superplasticizer exhibited higher delays where as in the case of final setting times without superplasticizer OPC and PSC followed similar delaying trends and with the addition of superplasticizer along with microsilica to OPC and PSC exhibited almost similar level of delays in setting times.
Fig. 5.66 Variation of Setting Times in PSC and OPC Samples with Partial Replacement by Rice Husk Ash

From Fig. 5.66 the variations in the setting times are presented with the replacement by rice husk ash. The initial setting times followed an accelerated trend without the addition of superplasticizer. With the addition of the superplasticizer to PSC there was a slight increase in the setting times and then it started declining with increase in RHA content where as in the case of OPC the setting times started declining and are lesser than PSC.

The final setting times followed a declining trend in OPC with RHA and there was a slight increase in the final setting times with 5% replacement of RHA and then it started declining with further increase in RHA percentage. With the addition of the...
superplasticizer to OPC and PSC the final setting times followed similar early setting trends and this decrease is slightly more in the case of PSC.

Though all the samples made with different types of cements i.e. portland slag cement and ordinary portland cement by partial replacement of chemical (superplasticizer) and mineral admixtures like fly ash, ground granulated blast furnace slag, microsilica and rice husk ash either accelerate or retard the setting process, rarely they exceed the significant values. The values in setting times of all these samples under consideration are within the range of standards specified.

5.5.2 SOUNDNESS TEST

Soundness test results of all the samples made with partial replacement of portland slag cement and ordinary portland cement by different mineral admixtures without and with the presence of chemical admixture are presented and discussed in detail and the variations of these values ranges between a very small band width. The Le-Chatelier's test results of soundness of different types of cements vary proportionately with the concentration of cement. But these variations are considered as meager when compared to the significant value, i.e., 10 mm in all the combinations that are studied and hence, there is no appreciable change in the volume of the samples is observed and finally all the samples considered are sound.

5.5.3 COMPRESSIVE STRENGTH

In the present investigation the percentage replacement of both the types of cements by different admixtures is carried out only up to 15%, but these replacements will give an optimum dosage of replacement which generally differs from one admixture to another admixture. In some types of admixtures the compressive strength increases with the increase in percentage replacements and with the age. This increase will continue up to certain amount of replacement and then starts diminishing, which is considered as optimum dosage replacement.

The comparisons between two types of cements used with different admixtures without and with the presence of superplasticizer are presented in pictorial representation in the following sections from Fig. 5.67 to Fig. 5.70.
Comparison of compressive strengths of PSC and OPC mortar cubes with partial replacement by fly ash, ground granulated blast furnace slag, microsilica and rice husk ash without and with superplasticizer are presented in Fig. 5.67 (a) and (b), Fig. 5.68 (a) and (b), Fig. 5.69 (a) and (b) and Fig. 5.70(a) and (b) respectively.

![Graph showing comparison of PSC and OPC mortar cubes with partial replacement by fly ash without superplasticizer.]

![Graph showing comparison of PSC and OPC mortar cubes with partial replacement by fly ash with superplasticizer.]

Fig. 5.67(a) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Fly Ash without Superplasticizer

Fig. 5.67(b) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Fly Ash with Superplasticizer
Fig. 5.68(a) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Ground Granulated Blast Furnace Slag without Superplasticizer

Fig. 5.68(b) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Ground Granulated Blast Furnace Slag with Superplasticizer
Fig. 5.69(a) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Microsilica without Superplasticizer

Fig. 5.69(b) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Microsilica with Superplasticizer
Fig. 5.70(a) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Rice Husk Ash without Superplasticizer

Fig. 5.70(b) Comparison of PSC and OPC Mortar Cubes with Partial Replacement by Rice Husk Ash with Superplasticizer
From the Fig. 5.67(a) and Fig. 5.67(b) it can be clearly identified that both in the case of portland slag cement and ordinary portland cement the compressive strengths are increasing with the increase in the dosage replacement by fly ash as the age prolongs. The compressive strengths exhibited by mortar cubes prepared by ordinary portland cement are more than that of portland slag cement at the early ages i.e., at 3 days, 7 days and 28 days where as this changes at 90 days and 365 days showing an increase in the portland slag cement mortar cubes. Almost similar trends are found in the case of ground granulated blast furnace slag which are evident from Fig. 5.68(a) and Fig. 5.68(b).

The variations of compressive strengths with microsilica replacement are presented in Fig. 5.69(a) and Fig. 5.69(b) without and with superplasticizer respectively. All the combinations exhibited raising trend of compressive strengths with the increase in the dosage of microsilica replacement up to 10% and at 15% the strength gain was reduced when compared to 10% both in the case of OPC and PSC. So, 10% replacement level can be considered as an optimum dosage replacement among 5%, 10% and 15%. In the early ages the strength gain was significant in the case of mortar cubes prepared by ordinary portland cement and as the age prolongs to 90 days and one year, higher strength gain characteristic is observed in portland slag cement mortar cubes.

Fig. 5.70(a) and Fig. 5.70(b) are presenting the variations in the compressive strengths without and with superplasticizer with replacement by rice husk ash. It can be observed from the figures that the compressive strengths started increasing with the increase in the dosage of rice husk ash up to 10% replacement and they started declining with further increase up to 15% both in the case of OPC and PSC. At 15% replacement a significant decrease in the strengths can be identified with PSC at all ages and OPC also at most of the ages. So, 15% replacement is not advisable and 10% replacement can be considered as optimum. Just as in the case of microsilica here also early age strength is more in OPC mortar cubes and later age strength gaining is exhibited by PSC mortar cubes even up to one year.

In the present investigation for the admixtures fly ash and ground granulated blast furnace slag the compressive strengths are increasing with the increase in the percentage replacement of different cements. So, the investigation has not prolonged up
to a level of optimum dosage, where as in the case of other two admixtures i.e. microsilica and rice husk ash, the compressive strength values started diminishing after the percentage replacement increased from 10% to 15%. The combination of mortar cubes prepared by 10% replacement levels can be considered as optimum combination in the respective cements both without and with the presence of superplasticizer. The percentage replacement by 10% can be considered as optimum dosage of replacement among 5%, 10% and 15% for microsilica and rice husk ash.

5.5.4 DURABILITY PROPERTIES

Although concrete was once regarded as a durable material with no need of its maintenance, it is now generally accepted that structural concrete does not have an indefinite life, i.e. it deteriorates (Naville, 1987). Similar is the case with mortar also. Durable mortar will retain its original form, quality and serviceability when exposed to the environment. Thus like any other material, the performance of mortar also changes with time and this process gained more importance.

In the present investigation, resistance offered by the mortar cubes against acid attack, alkaline attack, sulphate attack and chloride permeability have been studied in detail. With the increase in the replacement levels the resistance offered is also increased in most of the cases and mortar cubes prepared by portland slag cement are offering more resistance than ordinary portland cement which are evident from the results presented in previous sections.

5.5.5 SCANNING ELECTRON MICROSCOPY OF SAMPLES

A Scanning Electron Microscope (SEM) is a type of electron microscope that images a solid sample by scanning it with a beam of electrons in a raster scan pattern. The electrons interact with atoms that make up the solid sample producing signals that contain information about the solid samples surface morphology, composition and other properties such as electrical conductivity. Most of the samples prepared out of different combinations of admixtures and cements show calcium silicate formation in them.

The calcium silicate paste show well defined regions of C – S – H and CH. The (Ca/Si) ratios found for the C – S – H vary irregularly from point to point and increase with the voltage used to accelerate the electrons. As in all analyses of heterogeneous
materials by this method, the choice of the voltage rests on a compromise; it must be high enough to excite all the elements adequately, but low enough to produce an interaction volume sufficiently small that single phases can be analyzed. The present investigation clearly demonstrates that mean (Ca/Si) ratio for C₃S ranges from 1.4 at 6KV to around 2.0 at 25 KV. The totals obtained in SEM analysis of C – S – H in C₃S is around 70-75% and some time even slightly more. The net effect of SEM analysis further indicate an increase in the pozzolanic activity, increase in the strength characteristics with the formation of dense structure with decrease of pore spaces.

In the present investigation along with SEM analysis EDS (Energy Dispersive Spectroscope) is carried out, from which the various elements present in the samples are clearly identified.

5.5.6 X-RAY DIFFRACTION ANALYSIS OF SAMPLES

Although X-ray diffractometry does not provide any reliable quantitative information, the technique is sensitive. The X-ray diffraction (XRD) technique offers a convenient way to determine the mineralogical analysis of crystalline solids. If a crystalline mineral is exposed to X-rays of a particular wave length, the layers of atoms diffract the rays and produce a pattern of peaks, which is characteristic of the mineral. The horizontal scale (diffraction angle) of a typical XRD pattern gives the crystal lattice spacing, the vertical scale (peak height) gives the intensity of the diffracted ray. When the specimen being X-rayed contains more than one mineral the intensity of characteristics peaks from the individual minerals are proportional to the amount.

Standard data base (JCPDS data base) for X-ray power diffraction enables phase identification for a large variety of crystalline phases in a sample. The various figures of XRD analysis illustrate the XRD diffractograms for various investigated samples. The results of the diffraction peaks of the various samples are highly varied indicating that the samples contain variety of crystalline phases.

The intensity of XRD peaks of different additives are compared with standard portland slag cement and ordinary portland cement samples. The results indicate that the peaks are broadened or slightly decreased or diminished depending up on the additive chemical constituents reactions with Ca(OH)₂.
The basic reactions of all the additives with portland slag cement or ordinary portland cement may be represented as below:

\[ \text{C}_3\text{S} + \text{H} \xrightarrow{\text{Hydration}} \text{C-S-H} + \text{CaOH} \]

\[ \text{CaOH} + \text{S} \xrightarrow{\text{Additive}} \text{Hydration} \quad \text{C-S-H} \quad \text{(Silica form constituent)} \]

\[ \text{CaOH} + \text{A} \xrightarrow{\text{Additive}} \text{Hydration} \quad \text{C-A-H} \quad \text{(Alumina form constituent)} \]

5.6 EVALUATION OF MECHANICAL AND DURABILITY PROPERTIES OF PORTLAND SLAG CEMENT WITH 10% REPLACEMENT BY DIFFERENT ADMIXTURES

Based on the investigations done and discussions presented in the previous sections it is clear that out of the various admixtures used fly ash and ground granulated blast furnace slag are exhibiting better strength at 15% replacement dosage both with portland slag cement and ordinary portland cement where as in the case of microsilica and rice husk ash better results are appearing at 10% replacement level only. So, in the present investigation an attempt has also been made to find out which admixture replacement by 10% in portland slag cement is performing in a better manner out of these four admixtures as portland slag cement is giving good strength gain than that of ordinary portland cement. Based on the experimental results, graphical models were elaborated to study the strength of mortar cubes with partial replacement of cement by different admixtures with 10% of total powder content by weight.

Mechanical properties of cement at different ages made with 10% replacement of different mineral admixtures with and without superplasticizer in portland slag cement are presented in Table 5.35 and Fig. 5.71 and Fig. 5.72 respectively and the durability properties are presented in Table 5.36, Table 5.37 and Fig. 5.73 respectively.

The variations in the setting times and compressive strengths are presented in Table 5.35 and in graphical form in Fig. 5.71 and Fig. 5.72 respectively.

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Table 5.35  Mechanical Properties of Portland Slag Cement at Different Ages Made with 10% Partial Replacement by Different Admixtures without and with Superplasticizer

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+Admixture</th>
<th>Initial Setting Time (minutes)</th>
<th>Final Setting Time (minutes)</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Day</td>
<td>7 Day</td>
</tr>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>133</td>
<td>217</td>
<td>22.50</td>
<td>26.20</td>
</tr>
<tr>
<td>2</td>
<td>90%PSC +10% FA</td>
<td>145</td>
<td>220</td>
<td>23.59</td>
<td>27.85</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% GGBS</td>
<td>140</td>
<td>232</td>
<td>22.02</td>
<td>27.04</td>
</tr>
<tr>
<td>4</td>
<td>90%PSC +10% MS</td>
<td>132</td>
<td>225</td>
<td>23.17</td>
<td>29.73</td>
</tr>
<tr>
<td>5</td>
<td>90%PSC +10% RHA</td>
<td>120</td>
<td>211</td>
<td>23.87</td>
<td>27.90</td>
</tr>
<tr>
<td>6</td>
<td>100%PSC +SP</td>
<td>135</td>
<td>235</td>
<td>22.99</td>
<td>28.84</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% FA+SP</td>
<td>165</td>
<td>260</td>
<td>23.46</td>
<td>29.40</td>
</tr>
<tr>
<td>8</td>
<td>90%PSC +10% GGBS+SP</td>
<td>160</td>
<td>256</td>
<td>24.59</td>
<td>31.14</td>
</tr>
<tr>
<td>9</td>
<td>90%PSC +10% MS+SP</td>
<td>150</td>
<td>255</td>
<td>24.53</td>
<td>31.15</td>
</tr>
<tr>
<td>10</td>
<td>90%PSC +10% RHA +SP</td>
<td>128</td>
<td>215</td>
<td>23.58</td>
<td>29.20</td>
</tr>
</tbody>
</table>

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Fig. 5.71 Variation of Setting Times with 10% Partial Replacement of Portland Slag Cement by Different Admixtures
Fig. 5.72 Variation of Compressive Strength of PSC Mortar Cubes at Different Ages made with 10% Partial Replacement by Different Admixtures
Table 5.36 Durability Properties of Cement Mortar Cubes at Different Ages Made with 10% Partial Replacement by Different Admixtures without and with Superplasticizer in Portland Slag Cement

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 day) (MPa)</th>
<th>Acid Test (MPa)</th>
<th>Alkaline Test (MPa)</th>
<th>Sulphate Test (MPa)</th>
<th>% Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>54.80</td>
<td>47.80</td>
<td>49.30</td>
<td>48.50</td>
<td>12.77</td>
<td>10.04</td>
<td>11.49</td>
</tr>
<tr>
<td>2</td>
<td>90%PSC +10% FA</td>
<td>59.24</td>
<td>52.80</td>
<td>54.20</td>
<td>53.60</td>
<td>10.87</td>
<td>08.51</td>
<td>09.52</td>
</tr>
<tr>
<td>3</td>
<td>90%PSC +10% GGBS</td>
<td>61.27</td>
<td>54.65</td>
<td>56.10</td>
<td>55.50</td>
<td>10.80</td>
<td>08.43</td>
<td>09.42</td>
</tr>
<tr>
<td>4</td>
<td>90%PSC +10% MS</td>
<td>60.54</td>
<td>54.90</td>
<td>55.40</td>
<td>54.65</td>
<td>09.82</td>
<td>08.49</td>
<td>09.73</td>
</tr>
<tr>
<td>5</td>
<td>90%PSC +10% RHA</td>
<td>58.78</td>
<td>52.60</td>
<td>53.25</td>
<td>52.80</td>
<td>10.51</td>
<td>09.41</td>
<td>10.17</td>
</tr>
<tr>
<td>6</td>
<td>100%PSC +SP</td>
<td>56.95</td>
<td>50.50</td>
<td>51.70</td>
<td>51.00</td>
<td>11.32</td>
<td>09.22</td>
<td>10.45</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC +10% FA +SP</td>
<td>62.54</td>
<td>56.40</td>
<td>57.60</td>
<td>56.92</td>
<td>09.82</td>
<td>07.89</td>
<td>08.98</td>
</tr>
<tr>
<td>8</td>
<td>90%PSC +10% GGBS +SP</td>
<td>62.42</td>
<td>56.50</td>
<td>58.00</td>
<td>57.10</td>
<td>09.48</td>
<td>07.08</td>
<td>08.52</td>
</tr>
<tr>
<td>9</td>
<td>90%PSC +10% MS +SP</td>
<td>64.21</td>
<td>57.85</td>
<td>59.50</td>
<td>58.85</td>
<td>09.90</td>
<td>07.33</td>
<td>08.35</td>
</tr>
<tr>
<td>10</td>
<td>90%PSC +10% RHA +SP</td>
<td>61.15</td>
<td>55.85</td>
<td>55.91</td>
<td>55.90</td>
<td>08.67</td>
<td>06.93</td>
<td>08.58</td>
</tr>
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</table>
Fig. 5.73 Variation of Compressive Strength with PSC at 90 Day to Acid, Alkali and Sulphate Tests with Different Admixtures
Table 5.37 Permeability of Chloride in Portland Slag Cement for Every 30 Minutes Interval up to 6 Hours by using “RCPT Apparatus” for 10% Dosage of Different Admixtures

<table>
<thead>
<tr>
<th>S. No</th>
<th>Cement + Admixture</th>
<th>$I_0$</th>
<th>$I_{30}$</th>
<th>$I_{60}$</th>
<th>$I_{90}$</th>
<th>$I_{120}$</th>
<th>$I_{150}$</th>
<th>$I_{180}$</th>
<th>$I_{210}$</th>
<th>$I_{240}$</th>
<th>$I_{270}$</th>
<th>$I_{300}$</th>
<th>$I_{330}$</th>
<th>$I_{360}$</th>
<th>$I_{CUMULATIVE}$ in mA</th>
<th>$I_{AVERAGE}$ in Coulombs</th>
<th>Penetrability of Chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%PSC</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>14</td>
<td>14</td>
<td>17</td>
<td>17</td>
<td></td>
<td></td>
<td>2.76</td>
<td>2484</td>
<td>MODERATE</td>
</tr>
<tr>
<td>2</td>
<td>90%PSC + 10% FA</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td>18</td>
<td></td>
<td></td>
<td>1.99</td>
<td>1791</td>
<td>LOW</td>
</tr>
<tr>
<td>3</td>
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<td>2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td></td>
<td></td>
<td>1.48</td>
<td>1332</td>
<td>LOW</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>90%PSC + 10% MS</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>11</td>
<td>16</td>
<td>18</td>
<td>19</td>
<td></td>
<td></td>
<td>1.85</td>
<td>1665</td>
<td>LOW</td>
</tr>
<tr>
<td>5</td>
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<td>16</td>
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<td></td>
<td>1.62</td>
<td>1458</td>
<td>LOW</td>
</tr>
<tr>
<td>6</td>
<td>100%PSC + SP</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
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<td>11</td>
<td></td>
<td></td>
<td>1.39</td>
<td>1251</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>90%PSC + 10% FA + SP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
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<td>9</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td></td>
<td>1.17</td>
<td>1053</td>
<td>LOW</td>
</tr>
<tr>
<td>8</td>
<td>90%PSC + 10% GGBS + SP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td></td>
<td>0.86</td>
<td>774</td>
<td>VERY LOW</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>90%PSC + 10% MS + SP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td>0.45</td>
<td>405</td>
<td>VERY LOW</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>90%PSC + 10% RHA + SP</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>8</td>
<td>12</td>
<td>12</td>
<td></td>
<td>1.36</td>
<td>1224</td>
<td>LOW</td>
<td></td>
</tr>
</tbody>
</table>
5.6.1 INITIAL AND FINAL SETTING TIMES

From the Table 5.35 and Fig. 5.71 it can be clear that initial setting times got delayed for all the admixtures both without and with the combination of superplasticizer except for rice husk ash and a significant change was observed in the case of 10% replacement by fly ash with superplasticizer and nearly a significant change in the combination of 10% ground granulated blast furnace slag with plasticizer along with portland slag cement.

Similarly final setting times got retarded for all the samples prepared by addition of different admixtures both without and with the combination of superplasticizer except for rice husk ash where these got accelerated by a negligible amount. The change observed is significant in the case of samples prepared by 10% fly ash with superplasticizer, ground granulated blast furnace slag with superplasticizer and microsilica with superplasticizer.

5.6.2 COMPRESSIVE STRENGTH

From the Table 5.35 and Fig. 5.72 it is evident that strength characteristics got enhanced with the partial replacement of portland slag cement by different admixtures both with the absence and presence of superplasticizer. Even without superplasticizer a significant improvement in the strength is observed in the case 10% replacement by fly ash, ground granulated blast furnace slag and microsilica and this improvement is higher in microsilica than other admixtures.

Similarly a significant enhancement in the compressive strength is noticed with the addition of the superplasticizer to these combinations and as the age prolongs to one year almost 20% strength gain is observed in the case of microsilica and 15% strength development is appearing with ground granulated blast furnace slag and fly ash.

5.6.3 DURABILITY PROPERTIES

An improved resistance to various attacks like acid, alkaline, sulphate and chloride attacks are identified from the results presented in Table 5.36 and Table 5.37.

From the results presented in Table 5.36 and Fig. 5.73 it is evident that the resistance offered is of the order alkaline followed by sulphate and then by acid attacks.
As the percentage loss in compressive strength is becoming less, more and more resistance is offered against that particular attack.

The resistance offered to chloride permeability is also becoming more with the addition of the superplasticizer along with the 10% replacement by different admixtures as the results are showing that the chloride permeability is changing from moderate to low and very low in some admixtures.

From the results presented microsilica if exhibiting more resistance to various attacks than other admixtures as the percentage loss in compressive strength is very low when compared to other admixtures and also chloride penetrability is low and very low without and with superplasticizer in the case of microsilica.

5.7 SUMMING UP

Performance of mortar samples with partial replacement of portland slag cement and ordinary portland cement by different admixtures like fly ash, ground granulated blast furnace slag, microsilica and rice husk ash without and with the presence of superplasticizer are presented in detail. The various aspects which are studied include mechanical properties, durability properties and morphology characteristics with the replacement by the above mentioned admixtures along with and without chemical admixture.

In the present investigation the replacement levels are varying from 5% to 15% replacement only with an increment of dosage by 5% each time with all the four mineral admixtures without and with the presence of chemical admixture. From the analysis of various investigations performed it can be concluded that in the case of microsilica and rice husk ash 10% replacement level is exhibiting better performance than 15%. So, 10% can be concluded as an optimum dosage of replacement among 5%, 10% and 15% for microsilica and rice husk ash, whereas in the case of fly ash and ground granulated blast furnace slag improvement in the performance is identified with the increase in the dosage replacement from 5% even upto 15% and among 5%, 10% and 15% replacement dosages 15% can be concluded as optimum dosage level. But, to know the exact optimum dosage replacement the investigation has to be continued furthermore by enhancing the dosage replacement level and continuing the similar analysis. In the
present investigation to maintain uniformity among all the admixtures used, the replacement levels are stopped upto 15% only.

All the mineral and chemical admixtures which are otherwise hazardous to the environment when they are let-out of the various industries are used for partial replacement of portland slag cement and ordinary portland cement through which economy and sustainability can be achieved.

The best combinations for the better replacement can be identified for the useage of the various byproducts from various industries in a sustainable manner.
CHAPTER VI

CONCLUDING REMARKS AND SCOPE FOR THE FURTHER STUDY

Based on the detailed investigation performed and discussions presented in the previous chapter, the following concluding remarks are drawn.

6.1 CONCLUDING REMARKS

6.1.1 When portland slag cement or ordinary portland cement are partially replaced by fly ash, without and with the addition of superplasticizer, both the initial and final setting times delayed with the increase in the percentage replacement from 5% to 15% and this is more in the case of portland slag cement than ordinary portland cement.

6.1.2 Amongst all the mortar cubes prepared by different combinations of fly ash replacement in portland slag cement and ordinary portland cement without and with superplasticizer, the combination 85% PSC+15%FA with superplasticizer is showing more compressive strength and also the resistance offered to various attacks like acid, alkaline, sulphate and chloride attacks is reasonably high when compared to other mortar cubes. The chloride penetrability is also changed from moderate to very low which in turn implies the durability properties are also enhanced. This improvement in the properties may be due to the formation of C-S-H gel along with different compounds of aluminium silicate which are also identified in SEM and XRD analysis.

6.1.3 When portland slag cement or ordinary portland cement is replaced by 15% fly ash, maximum strength gain characteristics are appearing with enhanced durability properties also. So, 15% replacement level can be considered as optimum among 5%, 10% and 15%.

6.1.4 When portland slag cement or ordinary portland cement is replaced by GGBS, both the initial and final setting times are showing an retarding trend, which is still enhanced with the addition of superplasticizer and the PSC samples are exhibiting higher retardation than OPC samples.
6.1.5 Comparison of portland slag cement and ordinary portland cement mortar cubes with partial replacement by ground granulated blast furnace slag without superplasticizer reveal that the cubes prepared by the combination of 85%PSC+15%GGBS are exhibiting higher compressive strengths than all the other combinations and this combination is viewing greater resistance to acid, alkaline, sulphate attacks and the permeability to chloride ions changes from moderate to very low levels which reflects that resistance to chloride ion penetration is also enhanced. But when a comparison is done between OPC and PSC, OPC is exhibiting better results upto 28 days, whereas enhanced quality is appearing in PSC as the age reaches 90 days and even one year.

6.1.6 With the increase in the percentage of partial replacement by ground granulated blast furnace slag an improvement in the compressive strengths are observed at later ages i.e. after 7 days and these values goes on increasing as the age prolongs even up to one year with all the combinations and 85%PSC+15%GGBS+SP is performing in a better manner than that of all the other combinations. The durability properties also showed improving resistance against acid, alkaline, sulphate and chloride attacks.

6.1.7 Among 5%, 10% and 15% replacement levels of GGBS, 15% is considered as optimum dosage replacement as it is showing higher compressive strength characteristics along with enhanced durability characteristics against acid, alkaline, sulphate and chloride attacks with increased bondage between different elements by the formation of additional increase in C-S-H gel and compounds of calcium silicate.

6.1.8 With the partial replacement of portland slag cement or ordinary portland cement by microsilica both the initial and final setting times adopted a delay in the setting process even without and with the presence of superplasticizer.

6.1.9 When a comparison of portland slag cement and ordinary portland cement mortar cubes with partial replacement by Microsilica without and with superplasticizer is carried out, it can be noted that the compressive strengths started raising up to certain scale replacement i.e. 10% after that a decreasing trend is observed in both the OPC and PSC cubes. The combination of 90%PSC+10%MS is considered as optimum as the compressive strength
values started decreasing with the further increase in dosage of microsilica. Durability properties also presented an enhancement in the resistance to acid, alkaline, sulphate and chloride attacks. Improvement in the properties is observed with the addition of superplasticizer.

6.1.10 When the percentage replacement is increased from 10% to 15% there appeared a slight declination in the compressive strengths and even the durability properties are also not exhibiting much resistance to various attacks. An insignificant decrease in strength variations are observed when dosage replacement is changing from 10% to 15%. Hence 10% replacement dosage is considered as an optimum dosage of replacement for microsilica both for portland slag cement and ordinary portland cement.

6.1.11 When portland slag cement or ordinary portland cement are partially replaced by rice husk ash, both the initial and final setting times accelerated most of the cases whereas a slight delay is appeared with the addition of superplasticizer in some cases when the replacement levels are changing from 5% to 15% as the superplasticizer is exhibiting its tendency in delaying the setting times.

6.1.12 Among the mortar cubes prepared by different combinations of rice husk ash replacement in portland slag cement and ordinary portland cement without and with superplasticizer, the combination 90%PSC+10%RHA is showing more enhancement in the compressive strengths and the resistance offered to various attacks like, acid, alkaline and sulphate has increased when the percentage replacement is changing to 10% and with 15% replacement a significant declining of the durability properties is appeared in most of the cases, but the chloride ions penetrability has reduced from moderate level to very low which is showing that the resistance offered is more than the other cubes. All these changes may be due to the formation of reaction compounds such as mullite with the addition of rice husk ash.

6.1.13 The positive improvement in the mechanical and durability properties is appearing when the partial replacement of rice husk ash is changing from 5% to 10%, but with the further increase to 15% the properties are not showing much improvement and the resistance offered is declining rather than enhancing. So, 10% replacement dosage is considered as an optimum dosage of replacement both in the case of portland slag cement and ordinary portland cement.
6.1.14 Ordinary portland cement is exhibiting higher strength gain characteristics up to an age of 28 days but portland slag cement shows improved strength at later ages i.e., beyond 28 days onwards and even up to one year.

6.1.15 Based on the various investigations conducted on portland slag cement and ordinary portland cement, the better improvement in the mechanical and durability properties is noticed with portland slag cement.

6.1.16 Out of all the admixtures used the combination of portland slag cement with 10% replacement by microsilica without and with superplasticizer is the best one, as it is showing resistance to acid attack, alkaline attack sulphate attack and chloride attack and also showing a significant increase in the compressive strength as the age prolongs even up to one year duration also.

6.1.17 With the addition of the superplasticizer to the combination of portland slag cement with 10% replacement by microsilica is exhibiting better durability properties and significant improvement in the strength characteristics than the other admixtures which is followed by ground granulated blast furnace slag and then by fly ash.

6.1.18 As the soundness results of all the samples made with partial replacement of portland slag cement and ordinary portland cement by different admixtures considered like fly ash, ground granulated blast furnace slag, microsilica and rice husk ash both without and with superplasticizer are not showing appreciable change in the volume, so all the samples considered are sound.

The present investigation has revealed that the use of waste materials like fly ash, ground granulated blast furnace slag, microsilica and rice husk ash which are otherwise hazardous to the environment may be profitably used as a partial replacement of cement, which leads to economy and durability of the structure. Utilization of industrial wastes in this manner enhances the protection of the environment to a large extent. An optimum consumption of these materials can be done without scarifying the quality of concrete or mortar to make them suitable as “Green Building Materials” and which eventually leads the world towards a Sustainable Cement Industry.
6.2 **SCOPE FOR THE FURTHER STUDY**

6.2.1 Similar type of analysis can be done with the increase in the percentage replacement of fly ash and ground granulated blast furnace slag to 20% and more to find the optimum dosage of replacement, so that it can be used more effectively.

6.2.2 By making use of the other by-products such as metakaolin, calcined clays etc., from various industries similar analysis can be carried out to find the optimum percentage of replacement for the effective utilization of industrial wastes which are otherwise hazardous to the environment.

6.2.3 Comparative study on various properties with partial replacement of different types of cements by different admixtures can be done.

6.2.4 Studies can be done to know the physical properties, particle size distribution, chemical composition, pozzolanic activity and hydration mechanism of various admixtures and ordinary portland cement or portland slag cement.

6.2.5 Studies can be conducted on the fresh properties like bleeding characteristics and workability of mortar or concrete containing different admixtures.

6.2.6 Effect of various types of admixtures on properties of hardened concrete like porosity and water absorption capacity can be studied.

6.2.7 Effect on strength characteristics like tensile strength and flexural strength can also be found out for mortar and concrete with partial replacement by different admixtures.

6.2.8 Durability properties such as creep and shrinkage, freezing and thawing resistance, corrosion resistance and carbonation effect can also be studied on similar types of mortar and concrete.
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EVALUATION OF MECHANICAL AND DURABILITY PROPERTIES OF PORTLAND SLAG CEMENT WITH PARTIAL REPLACEMENT OF CEMENT BY DIFFERENT MINERAL AND CHEMICAL ADMIXTURES

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ABSTRACT

The construction industry is now slowly becoming aware of the environmental issues and other sustainable development issues for cement and concrete industries. It is looking for the ways and means to develop building products, which will increase the life span and quality. In this regard the merits of using certain industrial by products such as fly ash, ground granulated blast furnace slag, microsilica, and rice husk ash have been well recognized by the construction industry.

Therefore, it should be obvious that certain scale cement replacement with industrial by products is highly advantageous from the stand point of cost, economy, energy efficiency, durability and overall ecological and environmental benefits. In the present investigation an attempt is made to find various properties based on the experimental results, mathematical models were elaborated to predict the strength of mortar cubes with partial replacement of cement by different admixtures with 5% of total powder content by weight. Strength of cubes with Portland Slag Cement (PSC), after 3, 7, 28, 90 days and 360 days of curing and also durability tests after 60 days, were analysed to evaluate the effect of addition content, the time of curing and the compressive strength changes.

The investigation revealed that use of waste materials like fly ash, ground granulated blast furnace slag, microsilica and rice husk ash, which are otherwise hazardous to the environment may be used as a partial replacement of cement, which leads to economy and in addition by utilizing the industrial wastes in the useful manner the environment pollution is also reduced to great extent and which leads to sustainable development. Out of all these admixtures used microsilica gives best results when compared to other admixtures used with and without super plasticizer.

KEYWORDS: Compressive Strength, Durability, Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Micro Silica (MS), Rice Husk Ash (RHA), Superplasticizer

INTRODUCTION

The development of the construction industry in the global level needs more and more quantity of cement for sustainable growth. But, the production of each tonne of cement clinker releases one tonne of carbon dioxide, which affects the earth’s ecosystem\(^1\). Thus, increasing production of Ordinary Portland Cement (OPC) worldwide is aggravating the problems associated with its production and use. The addition of the pozzolanic materials with OPC, a century old practice, is an alternative practice in the construction industry.
Investigations were undertaken to establish the possibilities of using a much higher amount of flyash content in combination with fluorogypsum, lime sludge and portland cement to enhance the physico-chemical properties of cementitious binder. The experimental results indicated that the addition of FA in concrete improves the durability properties of concrete. One of the greatest drawbacks while using flyash as pozzolanic material in concrete is the early age performance of concrete.

The early age strength development of flyash blended concrete shows poor performance than the ordinary concrete. The development of ternary blends made by a superfine mineral admixture like silica fume (SF) is an alternative possible way to overcome the drawback of binary blends. The SF in the ternary blend improves the early age performance of concrete and the flyash is continuously improving the properties of hardened concrete. According to several researchers, ternary blends are vastly superior to portland cement concrete in terms of durability of structures.

The development of ternary blended cement has been the subject of investigation for the past three decades. Some of the developed countries are currently producing the ternary blended cement including a combination of flyash, slag and silica fume. The deterioration of concrete due to sulphuric acid attack is by leaching out of dissolved constituents of hardened concrete leading to loss of strength eventually initiating rapid deterioration.

The rate of chemical attack on concrete is a function of pH of the aggressive fluid and permeability of concrete (Neville 2003). The replacement of cement in the binary system using silica fume was suggested as 4%, 8% and 12% of the total powder content by weight. It was analysed by the test results that the compressive strength and the splitting tensile strength were related together and the 0.5 power relationship was found to be inaccurate in all the ternary blended combinations.

MATERIALS AND METHODS

Portland slag cement is obtained by mixing blast furnace slag, cement clinker and gypsum and grinding them together to get intimately mixed cement. The quantity of slag varies from 30-70%. The gain of strength of PSC is somewhat slower than OPC. Cement used in the present investigation is Ultratech. The sand used throughout the experimental work was obtained from the river Swarnamukhi near Tirupati, Chittoor district, Andhra Pradesh.

This type of sand was used by the many of researchers as an ingredient in cement mortar which is tested according to IS 650:1966 specifications. The characteristics of water were analyzed according to the standard methods for the examination of water. The different admixtures used are Fly ash (FA), Ground Granulated Blast furnace Slag (GGBS), Microsilica, Rice husk ash (RHA) and super plasticizer conforming to IS 9103:1999. Super plasticizer is based on a blend of specially selected organic polymers.

It is instantly dispersed in water. The various tests conducted and the equipment used for the test are given in the Table 1. These standard experimental procedures laid down in the standard codes, like IS, ASTM and BS codes were adopted for the determination of normal consistency, Initial and Final setting times, Soundness of Cement, Compressive Strength of cement mortar cubes.

The various durability tests conducted were Acid test, Alkaline test, Sulphate test and Rapid Chloride Permeability Test respectively. The specimens were tested for compressive strength duly following the procedure prescribed in IS 516:1959.

For Acid test the various samples prepared are immersed in water which contains 5% of HCL in it by weight of water for 60 days, after a normal curing of 28 days. The compressive strength and loss of weight are determined after the
Evaluation of Mechanical and Durability Properties of Portland Slag Cement with Partial Replacement of Cement by Different Mineral and Chemical Admixtures

completion of 90 days. For Alkaline test the various samples prepared are immersed in water which contains 5% of NaOH in it by weight of water for 60 days, after a normal curing of 28 days.

The compressive strength and loss of weight are determined after the completion of 90 days. For Sulphate test the various samples prepared are immersed in water which contains 5% of MgSO₄ and 5% of Na₂SO₄ in it by weight of water for 60 days, after a normal curing of 28 days.

The compressive strength and loss of weight are determined after the completion of 90 days. The rapid chloride permeability test for different mortar mixtures was carried out as per ASTM C-1202-97. This test method covers the determination of the electrical conductance of mortar to provide a rapid indication of its resistance to penetration of chloride ions.

<table>
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<th>Table 1: Details of the Various Experiments and Equipment Used</th>
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RESULTS AND DISCUSSIONS

The results of the present investigation are presented both in tabular and graphical forms. In order to facilitate the analysis, interpretation of the results is carried out at each phase of the experimental work.

This interpretation of the results obtained is based on the current knowledge available in the literature as well as on the nature of results obtained. The significance of the result is assessed with reference to the standards specified by the relevant IS codes.

The averages of both the initial and final setting time of three samples prepared with different cements replacement by 5% of fly ash, ground granulated blast furnace slag, microsilica, rice husk ash and also with chemical admixtures of superplasticizer are compared with ordinary cements.

If the difference is less than 30 minutes, the change is considered to be insignificant and if it is more than 30 minutes, the change is considered to be significant. The average compressive strength of at least three cubes prepared with mineral and chemical admixtures under consideration is compared with that of three cubes prepared with ordinary cements.

If the difference in the strength is less than 10%, it is considered to be insignificant and if it is greater than 10%, it is considered to be significant.

The average soundness test results of three samples prepared with different type of cements replaced with mineral and chemical admixtures under consideration are compared with that of three similar ordinary cements. The unsoundness of the specific sample, made with mineral and chemical admixtures is significant if the result of Le-Chatelier's soundness test is more than 10 mm.

Test results of initial and final setting times, soundness and percentage change in compressive strengths are presented in Table 2 and Figure 1 and Figure 2. Durability tests (Acid Test, Alkaline Test and Sulphate Test) regarding compressive strength of different types of cement mortar cubes with replacement of mineral and chemical admixtures are presented in the Table 3 and Figure 3. Results of Rapid Chloride Permeability Test are presented in Table 4 respectively.
Table 2: Initial and Final Setting Times, Soundness of Cement, Compressive Strength and Percent Change in Compressive Strength of Cement Mortar Cubes at Different Ages Made with 5% Replacement of Mineral Admixtures with and Without Superplasticizer in Portland Slag Cement

<table>
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<tr>
<th></th>
<th>Initial Setting Time (min)</th>
<th>Final Setting Time (min)</th>
<th>Soundness</th>
<th>Compressive Strength (MPa)</th>
<th>Percent Change in Compressive Strength (%)</th>
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Note: PSC - Portland Slag Cement, FA - Fly Ash, GGBS - Ground Granulated Blast Furnace Slag, MS - Microsilica, RHA - Rice Husk Ash, SP - Super Plasticizer
Evaluation of Mechanical and Durability Properties of Portland Slag Cement with Partial Replacement of Cement by Different Mineral and Chemical Admixtures

Figure 1: Variation of Initial and Final Setting Times in the Portland Slag Cement with Partial Replacement of Different Admixtures with and without Superplasticizer

Figure 2: Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with 5% Replacement of Admixtures with and without Superplasticizer in Portland Slag Cement

Figure 3: Comparison of Compressive Strength Values at 90 Days and After Acid, Alkaline and Sulphate Test
Table 3: Durability Tests of the Portland Slag Cement made with 5% Replacement of Mineral Admixtures with and without Superplasticizer on the Compressive Strength

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Table 4: Permeability of Chloride in Portland Slag Cement for every 30 Minutes Interval up to 6 hours by using “RCPT Apparatus”

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<td>7</td>
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<td>1.82</td>
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**Percentage Loss in Weight for Portland Slag Cement**

- When the Portland Slag Cement is used to make mortar cubes the percentage weight loss is marginal. The percentage weight loss is 1.43, 0.56 and 0.56 in acid, alkaline and sulphate test performed respectively.
- When the Portland Slag Cement is replaced by 5% fly ash in cement the percentage weight loss is marginal. The weight loss is in the following order sulphate test is greater than that of alkaline and acid test.
- When the Portland Slag Cement is replaced by 5% slag in cement the percentage weight loss is 2.06, 1.4 and 1.25 for alkaline, sulphate and acid test respectively.
- When the Portland Slag Cement is replaced by 5% microsilica in cement the percentage weight loss for acid test, alkaline and sulphate test is marginal.
- When the Portland Slag Cement is replaced by 5% rice husk ash in cement the percentage weight loss is in the following order sulphate test is greater than acid and alkaline test.
- When the Portland Slag Cement is replaced by 5% superplasticizer in cement the percentage weight loss is very less.
- When the Portland Slag Cement is replaced by 5% fly ash in cement when addition of superplasticizer the percentage weight loss is 1.3, 1.1 and 1.0 for alkaline, acid and sulphate test.
- When the Portland Slag Cement is replaced by 5% slag in cement with the addition of superplasticizer the percentage weight loss is 1.09, 1.05 and 0.78 in acid, alkaline and sulphate test performed respectively.
- When the Portland Slag Cement is used to make cement mortar by replacing 5% microsilica with the addition of superplasticizer, the percentage weight loss is marginal. The percentage weight loss is 0.7, 0.65 and 0.03 in acid, alkaline and sulphate test performed respectively.
- When the Portland Slag Cement is replaced by 5% rice husk ash with the addition of superplasticizer in cement mortar the percentage weight loss in acid, alkaline and sulphate test is negligible.
From Table 2 and Figure 2 it is clear that the compressive strength is increased from 3 days to 365 days in all the mortar cubes which are prepared by the partial replacement of cement by different mineral and chemical admixtures. But when compared to the other admixtures compressive strength is increased much in the case of mortar cubes prepared with partial replacement of cement by microsilica both with and without superplasticizer.

When the Portland Slag Cement is replaced by 5% microsilica in cement the percentage weight loss for acid, alkaline and sulphate test is marginal. When the Portland Slag Cement is used to make cement mortar by replacing 5% microsilica with the addition of superplasticizer, the percentage weight loss is marginal. The percentage weight loss is 0.7, 0.65 and 0.03 in acid, alkaline and sulphate test performed respectively and these are very less when compared to the other combinations.

According to the results obtained from the Table 4 it is clear that the mortar cubes prepared by the combination of portland slag cement with 5% replacement by microsilica with the addition of the superplasticizer shows much resistance to the permeability of chlorine followed by portland slag cement with superplasticizer alone.

CONCLUSIONS

All the mineral and chemical admixtures which are otherwise hazardous to the environment when they are let-out of the various industries can be used for partial replacement of Portland slag cement through which economy and sustainability can be achieved.

Out of all the admixtures used the combination of Portland slag cement with partial replacement by microsilica with superplasticizer is the best one as it is showing resistance to acid attack, alkaline attack and sulphate attack and showing increase in the compressive strength as the age prolongs up to one year duration also.

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Evaluation of Mechanical and Durability Properties of Portland Slag Cement with Partial Replacement of Cement by Different Mineral and Chemical Admixtures


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Influence of Microsilica on the Properties of Ordinary Portland cement and Portland Slag Cement with and without Super plasticizers

B.Damodhara Reddy, S.Aruna Jyothy, I.V.Ramana Reddy

Abstract— The development of the construction industry in the global level needs more and more quantity of cement for sustainable growth. But, the production of each tonne of cement clinker releases one tonne of carbon dioxide, which affects the earth's ecosystem. The construction industry is now slowly becoming aware of the environmental issues and other sustainable development issues for cement and concrete industries. It is looking for the ways and means to develop building products, which will increase the life span and quality. In this regard the merits of using certain industrial by products such as fly ash, ground granulated blast furnace slag, microsilica, and rice husk ash have been well recognized by the construction industry. Therefore, it should be obvious that certain scale cement replacement with industrial by products is highly advantageous from the stand point of cost, economy, energy efficiency, durability and overall ecological and environmental benefits. In the present investigation an attempt is made to find various properties based on the experimental results, mathematical models were elaborated to predict the strength of mortar cubes with partial replacement of cement by Microsilica admixture with 5%, 10% and 15% of total powder content by weight both with and without the presence of Superplastizier. Strength of cubes with Ordinary Portland Cement (OPC) and Portland Slag Cement (PSC), after 3, 7, 28, 90 days and 365 days of curing and also durability tests after 60 days, were analysed to evaluate the effect of addition content, the time of curing and the compressive strength changes. The investigation revealed that use of one of such waste materials microsilica which is a waste material obtained from alloy industries can be used for partial replacement of cement, which leads to economy and in addition by utilizing the industrial wastes in the useful manner the environmental pollution is also reduced to great extent and which leads to sustainable development. Test results indicate that the use of microsilica has improved the performance of cement in strength as well as in durability aspect.

Key Words — Compressive Strength, Durability, Ordinary Portland cement (OPC), Portland Slag cement (PSC), Microsilica (MS).

1. INTRODUCTION

Concrete is a widely used construction material for various types of structures due to its structural stability and strength. The usage, behavior as well as the durability of concrete structures, built during the last first half of the century with Ordinary Portland Cement (OPC) and plain round bars of mild steel, the ease of procuring the constituent materials (whatever may be their qualities) of concrete and the knowledge that almost any combination of the constituents leads to a mass of concrete have bred contempt. Strength was stressed without a thought on the durability of structures. As a consequence of the liberties taken, the durability of concrete and concrete structures is on a southward journey; a journey that seems to have gained momentum on its path to self-destruction [1]. It is known that permeability controls deterioration of concrete in aggressive environments, because the processes of such deterioration as carbonation, chloride attack and sulfates attack are governed by the fluid transportation in concrete. Fillers and pozzolanic materials are introduced to improve the strength and other properties of concrete for necessary conditions [2]. The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor of green house effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material [3]. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Substantial energy and cost savings can result when industrial by products are used as a partial replacement of cement. Fly ash, Ground Granulated Blast furnace Slag, Rice Husk ash, High Reactive Met kaolin, Silica fume are some of the pozzolanic materials which can be used in concrete as partial replacement of cement [4]. When pozzolanic materials are incorporated to concrete, the silica present in these materials are act with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C-S-H), which improve durability and the mechanical properties of concrete [5]. Silica fume or micro silica is a byproduct of the smelting process in the silicon and ferrosilicon industry. Micro silica has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. By using silica fume along with superplasticizers, it is relatively easier to obtain compressive strengths of order of 100-150MPa in laboratory. Addition of Micro silica to concrete improves the durability of concrete through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to sulfate attack. Improvement in durability will also improve the ability of silica fume concrete in protecting the embedded steel from corrosion [6]. Tiwari et al presented a research study carried out to improve the early age compressive
Influence of Microsilica on the Properties of Ordinary Portland Cement and Portland Slag Cement with and without Superplasticizers

The replacement of cement in the binary system using silica fume was suggested as 4%, 8% and 12% of the total powder content by weight. It was analysed by the test results that the compressive strength and the splitting tensile strength were related together and the 0.5 power relationship was found to be inaccurate in all the ternary blended combinations [8]. The development of ternary blends made by a superfine mineral admixture like silica fume (SF) is an alternative possible way to overcome the drawback of binary blends. The SF in the ternary blend improves the early age performance of concrete and the flyash is continuously improving the properties of hardened concrete [9]. According to several researchers, ternary blends are vastly superior to portland cement concrete in terms of durability of structures [10]. The development of ternary blended cement has been the subject of investigation for the past three decades [11]. Some of the developed countries are currently producing the ternary blended cement including a combination of flyash, slag and silica fume [12].

II. MATERIALS AND METHODS

The Ordinary Portland Cement (OPC) (43 Grade as per IS:8112-1989) [13] was used in the investigation. Portland Slag Cement (PSC) is obtained by mixing blast furnace slag, cement clinker and gypsum and grinding them together to get intimately mixed cement. The quantity of slag varies from 30-70%. The sand used throughout the experimental work was obtained from the river Swarnamukhi near Tirupati, Chittoor district, Andhra Pradesh. The different admixtures used were Microsilica and super plasticizer conforming to IS 9103:1999 [14]. Super plasticizer is based on a blend of specially selected organic polymers. It is instantly dispersed in water.

The various tests conducted and the equipment used for the test are given in the Table. These standard experimental procedures laid down in the standard codes, like IS, ASTM and BS codes were adopted for the determination of normal consistency, Initial and Final setting times, Soundness of Cement, Compressive Strength of cement mortar cubes. The various durability tests conducted were Acid test, Alkaline test, Sulphate test and Rapid Chloride Permeability Test respectively. For Acid test the various samples prepared are immersed in water which contains 10% of HCl in it by weight of water for 60 days, after a normal curing of 28 days. The compressive strength and loss of weight are determined after the completion of 90 days. For Alkaline test the various samples prepared are immersed in water which contains 5% of NaOH in it by weight of water for 60 days, after a normal curing of 28 days. The compressive strength and loss of weight are determined after the completion of 90 days. For Sulphate test the various samples prepared are immersed in water which contains 5% of MgSO₄ and 5% of Na₂SO₄ in it by weight of water for 60 days, after a normal curing of 28 days. The compressive strength and loss of weight are determined after the completion of 90 days. The rapid chloride permeability test for different mortar mixtures was carried out as per ASTM C1202-97. This test method covers the determination of the electrical conductance of mortar to provide a rapid indication of its resistance to penetration of chloride ions.

III. RESULTS AND DISCUSSION

The results of the present investigation are presented both in tabular and graphical forms. In order to facilitate the analysis, interpretation of the results is carried out at each phase of the experimental work. This interpretation of the results obtained is based on the current knowledge available in the literature as well as on the nature of results obtained.

The significance of the result is assessed with reference to the standards specified by the relevant IS codes. The averages of both the initial and final setting time of three samples prepared with different cements replacement by 5%, 10% and 15% of microsilica, and also with chemical admixtures of superplasticizer are compared with both the types of cements. If the difference is less than 30 minutes, the change is considered to be insignificant and if it is more than 30 minutes, the change is considered to be significant.

The average compressive strength of at least three cubes prepared with mineral and chemical admixtures under consideration is compared with that of three cubes prepared with ordinary cements. If the difference in the strength is less than 10%, it is considered to be insignificant and if it is greater than 10%, it is considered to be significant.

The average soundness test results of three samples prepared with different type of cements replaced with mineral and chemical admixtures under consideration is compared with that of three cubes prepared with ordinary cements. If the difference in the strength is less than 10%, it is considered to be insignificant and if it is greater than 10%, it is considered to be significant.

The average chloride permeability test results of three samples prepared with different type of cements replaced with mineral and chemical admixtures under consideration is compared with that of three similar ordinary cements. The unsoundness of the specific sample, made with mineral and chemical admixtures is significant if the result of Le Chatelier's soundness test is more than 10 mm.

Test results of initial and final setting times, soundness and percentage change in compressive strengths for Ordinary Portland cement and Portland Slag Cement are presented in Table 2. Variations of the compressive strengths are presented in Figures 1 and 2. Durability tests (Acid Test, Alkaline Test and Sulphate Test) regarding compressive strength of different types of cement mortar cubes with replacement are presented in the Table 3 and Figure 3 and Figure 4. Results of Rapid Chloride Permeability Test are presented in Table 4 respectively. Finally the comparison of ordinary Portland cement and Portland slag cement for 10% replacement with microsilica in the presence of superplasticizer are presented in Figure 5.

<table>
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<tr>
<th>S.No</th>
<th>Experiment Name</th>
<th>Equipment Used</th>
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<td>2</td>
<td>Soundness of cement</td>
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<td>Chloride Permeability</td>
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Table 1 Details of the Various Experiments and Equipment Used
Table 2 Initial and final setting times, soundness of cement, compressive strength and percent change in compressive strength of cement mortar cubes at different ages made with partial replacement of Microsilica (MS) with and without superplasticizer (SP) in OPC and PSC.

<table>
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<tr>
<th>S.N.</th>
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<th>Initial setting time (min)</th>
<th>Final setting time (min)</th>
<th>Soundness (mm)</th>
<th>Compressive strength MPa</th>
<th>Percent change in compressive strength</th>
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<td></td>
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<td>28day</td>
<td>90day</td>
<td>365 days</td>
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<td>1.00</td>
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<td>220</td>
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Figure 1 Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica with and without Superplasticizer in Ordinary Portland Cement.
Influence of Microsilica on the Properties of Ordinary Portland cement and Portland Slag Cement with and without Superplasticizers

Figure 2 Variation of Compressive Strength of Cement Mortar Cubes at Different Ages made with Partial Replacement of Microsilica with and without Superplasticizer in Portland Slag Cement

Table 3 Durability Tests results of the Mortar Cubes of OPC and PSC made with Partial Replacement of Microsilica with and without Superplasticizer

<table>
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<th>S.N.</th>
<th>Cement+ Admixture</th>
<th>Compressive Strength (90 days) MPa</th>
<th>Acid Test Mpa</th>
<th>Alkaline Test MPa</th>
<th>%Loss in Compressive Strength in Acid Test</th>
<th>% Loss in Compressive Strength in Alkaline Test</th>
<th>% Loss in Compressive Strength in Sulphate Test</th>
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<td>1</td>
<td>OPC</td>
<td>48.20</td>
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<td>51.86</td>
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<td>45.70</td>
<td>10.52</td>
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<td>53.46</td>
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<td>47.05</td>
<td>11.52</td>
<td>12.45</td>
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<td>49.92</td>
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<td>44.47</td>
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<td>44.60</td>
<td>44.10</td>
<td>43.50</td>
<td>11.23</td>
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<td>OPC +5% Microsilica +SP</td>
<td>53.46</td>
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<td>10.78</td>
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MS: Microsilica, SP: Superplasticizer
Table 4: Permeability of Chloride in OPC and PSC for every 30 minutes interval up to 6 hours by using "RCPT Apparatus"

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<th>1d</th>
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MS: Microsilica, SP: Superplasticizer

Figure 3: Comparison of Compressive strength Values for Ordinary Portland Cement at 90 Days and After Acid, Alkaline and Sulphate Test
Influence of Microsilica on the Properties of Ordinary Portland cement and Portland Slag Cement with and without Super plasticizers

From Table 2 and Figure 1 and Figure 2 it is clear that the compressive strength values for mortar cubes prepared by both the types of cements with partial replacement of cement by microsilica shows an increasing trend in 3 days, 7 days, 28 days, 90 days and 365 days upto 10% and then decline in the strength values to 15% with and without superplasticizer.

It is clearly observed from Table 3 and Figure 3 and Figure 4 that mortar cubes prepared with 10% replacement of cement by microsilica both with and without superplasticizer show much resistance to acid attack, alkaline attack and sulphate attack and also show very less permeability of chlorine also in the case of ordinary portland cement as well as portland slag cement which is shown in Table 4.
IV. CONCLUSION

Out of all the various combinations of both ordinary Portland cement and Portland slag cement with partial replacement by microsilica with superplasticizer and without superplasticizer the best one is OPC+10% Microsilica+Superplasticizer as it is showing resistance to acid attack, alkaline attack and sulphate attack and showing increase in the compressive strength as the age prolongs up to one year duration also.

REFERENCES


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