CHAPTER 5

RESULTS AND DISCUSSIONS ON DURABILITY PROPERTIES OF THE CONCRETE

5.1 INTRODUCTION

The results obtained from the experimental works are presented and discussed in this module. The effects of replacing various admixtures (fly ash, silica fume, rice husk ash, calcium nitrate), while preparing the concrete, on the important durability properties of the concrete such as sulphate attack, chloride attack, acid attack, corrosion etc are discussed in detail and compared with the conventional concrete specimens prepared for M25 and M30 grade of concrete.

5.2 DURABILITY OF THE CONCRETE

The durability of the concrete can be defined as its resistance to the deteriorating influences of both external and internal agencies. A durable concrete is the one which performs satisfactorily under anticipated exposure conditions during its entire service life span. The materials and mix proportions used should be such as to maintain its integrity and to protect the reinforcement bar embedded in the concrete from corrosion (Fattuhi and Hughes 1986). Even though the concrete is a durable material requiring a little or no maintenance in normal environment but when subjected to highly aggressive or hostile environments it has been found to deteriorate resulting in
premature failure of structures or reach as state requiring costly repairs. The main characteristics influencing the durability of the concrete is the permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances (Gambhir 2009).

Most of the durability problems in the concrete can be attributed to the volume change in the concrete. Volume change in the concrete is caused by many factors. The entire hydration process is nothing but an internal volume change, the effect of heat of hydration, the pozzolanic action, the sulphate attack, the carbonation, the moisture movement, all types of shrinkages, the effect of chlorides, corrosion of steel reinforcement and host of other aspects come under the preview of volume change in the concrete. The internal or external restraints to volume change in the concrete results in the cracks (Gambhir 2009).

5.3 PERMEABILITY OF THE CONCRETE

Permeability of concrete is the property by which water can penetrate into the pores of the concrete and in turn it may adversely affect the strength and durability properties of the concrete. When excess water in the concrete evaporates, it leaves voids inside the concrete element creating capillaries which are directly related to the concrete porosity. The quantity and volume of moisture which passes through the concrete depends on the concrete permeability. If the concrete becomes saturated with water then it is more vulnerable to frost action.
The penetration of weathering agents along with the water into the concrete may lead to corrosion of reinforcement bar embedded in the concrete which in turn weakens the structures. The penetration of materials along with the solution adversely affects the durability aspects of the concrete, i.e, calcium hydroxide leaches out and the aggressive liquids attack the concrete. The factors affecting the permeability of the concrete are formation of micro cracks in the transition zones, cracks generated through higher structural stresses, cracks formed due to corrosion of the reinforcement bar embedded in the concrete, atmospheric moisture, quality and purity of water used for making concrete etc.

The permeability of M25 grade of the conventional concrete is $7.60 \times 10^{-7}$ cm/sec after 28 days, $6.60 \times 10^{-7}$ cm/sec after 56 days, $6.10 \times 10^{-7}$ cm/sec after 90 days, $6.00 \times 10^{-7}$ cm/sec after 120 days and $5.20 \times 10^{-7}$ cm/sec after 180 days. The permeability of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is $6.80 \times 10^{-7}$ cm/sec after 28 days, $6.20 \times 10^{-7}$ cm/sec after 56 days, $5.80 \times 10^{-7}$ cm/sec after 90 days, $5.60 \times 10^{-7}$ cm/sec after 120 days and $5.10 \times 10^{-7}$ cm/sec after 180 days.

It was observed that the permeability of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 10.5%, 6.06%, 4.91%, 6.66% and 1.92% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.1. The mineral additives reduced the porosity of cement paste by pozzolanic action and the filler effect. The silica in the pozzolana state combined with the free-lime produced during the hydration of cement which resulted in the dense and
amorphous phase which progressively fills up the interstices in the pore structure of the paste (Andreas Leemann et al 2010).

Figure 5.1 Variation of permeability with age of M25 grade of concrete

The permeability of M30 grade of the conventional concrete is $6.80 \times 10^{-7}$ cm/sec after 28 days, $6.60 \times 10^{-7}$ cm/sec after 56 days, $6.40 \times 10^{-7}$ cm/sec after 90 days, $5.90 \times 10^{-7}$ cm/sec after 120 days and $5.80 \times 10^{-7}$ cm/sec after 180 days. The permeability of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is $6.50 \times 10^{-7}$ cm/sec after 28 days, $6.30 \times 10^{-7}$ cm/sec after 56 days, $6.00 \times 10^{-7}$ cm/sec after 90 days, $5.90 \times 10^{-7}$ cm/sec after 120 days and $5.80 \times 10^{-7}$ cm/sec after 180 days.

It was observed that the permeability of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 4.44%, 4.54%, 6.25%, 0.00% and 0.00% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.2. The reduced permeability of the concrete added with admixture is due to the modified
dense microstructure of the concrete achieved by the combined used of the mineral additives having ultrafine particles.

![Figure 5.2 Variation of permeability with age of M30 grade of concrete](image)

**Figure 5.2 Variation of permeability with age of M30 grade of concrete**

It may be concluded that the permeability was decreased with the replacement of the cement with admixtures. An inference was also made that the lower the air permeability of the concrete indicated a greater resistance to sulphate attack, chloride attack and acid attack. The quality of the concrete with respect to the durability property was measured in terms of permeability which was governed by the pore system (Mitsuru Saito et al 1994). It was the basic to its ability to resist chemical attack or acid attack or sulphate attack or chloride attack by external sources.
5.4 SULPHATE ATTACK OF THE CONCRETE

The sulphate attack is caused by the chemical reaction between sulphate ions and hydration products. The result of the chemical reaction is calcium sulpha aluminate hydrate, commonly referred to as ettringite (3CaO.A1₂O₃.3CaSO₄.32H₂O) which results in the reduction of bond strength and internal disintegration of the concrete. These solids (ettringite) have a very much higher volume up to 225% of the concrete specimen. As a consequence, stresses are produced in the concrete which may result in the breakdown of the cement paste and it ultimately results in the breakdown of the concrete. The sources of sulphate ion are such as sewage, salts in ground water, industrial waste, delayed release of the clinker during the cement production etc.

After the immersion of the concrete specimen in the sulphate solution for the entire test duration, a white patch was formed on the concrete specimen. This was because due to the free movement of water which carried the calcium sulphate towards the surface of the concrete specimen. The loss of weight due to sulphate attack of M25 grade of the conventional concrete is 0.53% after 28 days, 0.66% after 56 days, 0.72% after 90 days, 0.86% after 120 days and 0.94% after 180 days. The loss of weight due to sulphate attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.49% after 28 days, 0.20% after 56 days, 0.13% after 90 days, 0.23% after 120 days and 0.33% after 180 days.

It is observed that the loss of weight due to sulphate attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.04%, 0.46%, 0.59%, 0.63% and 0.61% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.3.
The compressive strength of M25 grade of the conventional concrete is 23.54 MPa after 28 days, 21.40 MPa after 56 days, 20.41 MPa after 90 days, 19.21 MPa after 120 days and 16.40 MPa after 180 days. The compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 30.44 MPa after 28 days, 30.19 MPa after 56 days, 29.59 MPa after 90 days, 29.28 MPa after 120 days and 29.27 MPa after 180 days.

It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 29.31%, 41.07%, 44.98%, 52.92% and 78.48% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.4. The decrease in compressive strength of the concrete was because a considerable bursting pressure was created on the surrounding concrete. It was due to the ettringite formation which leads to cracking (Andres Idiart et al 2011). Hairline cracks were developed on the concrete specimen. It
sometimes even leads to splitting of the concrete specimen (Nader Ghafoori et al 2008).

Figure 5.4  Variation of compressive strength with age of M25 grade of concrete due to sulphate attack

The loss of weight due to sulphate attack of M30 grade of the conventional concrete is 0.42% after 28 days, 0.51% after 56 days, 0.59% after 90 days, 0.69% after 120 days and 0.83% after 180 days. The loss of weight due to sulphate attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.38% after 28 days, 0.44% after 56 days, 0.49% after 90 days, 0.58% after 120 days and 0.69% after 180 days.
It is observed that the loss of weight due to sulphate attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.04%, 0.07%, 0.1%, 0.11% and 0.14% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.5.

Figure 5.5 Loss of weight of M30 grade of concrete due to sulphate attack

The compressive strength of M30 grade of the conventional concrete is 29.32 MPa after 28 days, 27.64 MPa after 56 days, 25.12 MPa after 90 days, 21.40 MPa after 120 days and 18.12 MPa after 180 days. The compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 34.42 MPa after 28 days, 33.18 MPa after 56 days, 33.02 MPa after 90 days, 32.72 MPa after 120 days and 32.40 MPa after 180 days.
It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 17.39%, 20.04%, 31.45%, 52.90% and 78.81% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.6. In few test specimens, bulging of the concrete were also noticed. The spalling of the cover of the concrete specimen was also observed in the test specimens. The bulging and the spalling lead to loss of compressive strength of the concrete test specimens.

![Figure 5.6  Variation of compressive strength with age of M30 grade of concrete due to sulphate attack](image)

With the replacement of 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate, the serious ill effects due to sulphate attack on the concrete were drastically decreased. The sulphate attack was significantly reduced by replacement of admixtures such as fly ash, silica
fume, rice husk ash and calcium nitrate in required proportions with the binding material cement (Andres et al 2011). From the results, it can be concluded that by using multicomponent blended concrete, the sulphate resistance of the concrete had been increased. Fattuhi and Hughes (1986) observed that the effect due to the sulphate attack was significantly reduced (3%-6%) with the replacement of the admixtures.

5.5 CHLORIDE ATTACK OF THE CONCRETE

Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. The statistics have indicated that over 40 per cent of failure of structures is due to the chloride attack which further leads to corrosion. The chloride enters the concrete from cement, water, aggregate and sometimes from admixtures. Chloride can also enter the concrete by diffusion from the environment. The amount of chloride required for initiating corrosion is partly dependent on the pH value of the pore water in the concrete (Shetty 2011).

The loss of weight due to chloride attack of M25 grade of the conventional concrete is 0.82% after 28 days, 0.78% after 56 days, 0.76% after 90 days, 0.69% after 120 days and 0.64% after 180 days. The loss of weight due to chloride attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.34% after 28 days, 0.32% after 56 days, 0.24% after 90 days, 0.21% after 120 days and 0.19% after 180 days. The presence of chlorides increases the shrinkage cracks in the concrete specimens. The penetration of chloride ions in excess of the threshold concentration value reduces the alkalinity of the concrete and breaks down the protective film (Santhakumar 2008) and leads to
disintegration and further leads to loss of weight of the concrete (Andreas Leemann et al 2010).

It is observed that the loss of weight due to chloride attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.48%, 0.46%, 0.52%, 0.48% and 0.45% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.7. The rate of loss of weight of the concrete specimens due to chloride attack is proportional to the severity of the exposure of the concrete specimens to the chloride solutions. Since the concrete specimens in immersed in the chloride solution for the entire test duration, the concrete in the cover region undergoes a significant amount of deterioration which sometimes leads to disintegration of the concrete and as a result, the loss of weight is more (Andreas Leemann et al 2010).

![Figure 5.7 Loss of weight of M25 grade of concrete due to chloride attack](image)
The compressive strength of M30 grade of the conventional concrete is 29.96 MPa after 28 days, 30.86 MPa after 56 days, 32.62 MPa after 90 days, 33.24 MPa after 120 days and 33.36 MPa after 180 days. The compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 32.07 MPa after 28 days, 32.82 MPa after 56 days, 33.22 MPa after 90 days, 33.91 MPa after 120 days and 34.02 MPa after 180 days.

It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 7.04%, 6.35%, 1.84%, 2.02% and 1.98% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.8.

![Figure 5.8 Variation of compressive strength with age of M25 grade of concrete due to chloride attack](image)
The loss of weight due to chloride attack of M30 grade of the conventional concrete is 0.73% after 28 days, 0.71% after 56 days, 0.62% after 90 days, 0.59% after 120 days and 0.51% after 180 days. The loss of weight due to chloride attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.30% after 28 days, 0.28% after 56 days, 0.20% after 90 days, 0.20% after 120 days and 0.16% after 180 days.

It is observed that the loss of weight due to chloride attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.43%, 0.43%, 0.42%, 0.39% and 0.35% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.9.

![Figure 5.9 Loss of weight of M30 grade of concrete due to chloride attack](image)

The compressive strength of M30 grade of the conventional concrete is 33.42 MPa after 28 days, 34.16 MPa after 56 days, 34.94 MPa after 90 days, 35.02 MPa after 120 days and 35.64 MPa after 180 days. The
compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 34.12 MPa after 28 days, 34.98 MPa after 56 days, 35.36 MPa after 90 days, 35.94 MPa after 120 days and 36.87 MPa after 180 days.

It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 2.09%, 2.40%, 1.20%, 2.63% and 3.45% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.10. It was observed that the compressive strength was increased and the loss of weight of the concrete was decreased in the concrete specimens prepared by using the admixtures because the especially by the addition of fly ash, they physically bind chloride ions and thus block their passage through the concrete cover.

Figure 5.10 Variation of compressive strength with age of M30 grade of concrete due to chloride attack
The main cause of loss of weight of the concrete specimen due to chloride attack was because of the porosity and permeability which increased the rate of penetration chloride ions. The particle packing minimized the volume of voids which physically prevented the permeation. By the addition of admixtures, the permeability was significantly reduced. Hence the effect due to the chloride attack both in terms of loss of weight of the concrete specimen and reduction in compressive strength was also considerably decreased (Fattuhi and Hughes 1986).

5.6 ACID ATTACK OF THE CONCRETE

The acid attack of the concrete is due to the presence of acids in subsoil and groundwater, acidic atmosphere in which the structure is built, acid stored in tanks, acid added during the manufacture of the concrete with or without the awareness. A pH value of less than 6 indicates the presence of acids in groundwater. Chemical attack generally occurs when calcium hydroxide present in the concrete is vigorously attacked. The acidic solutions both mineral (such as sulphuric, hydrochloric, nitric, and phosphoric chemicals) and organic (such as lactic, acetic, formic, tannic chemicals) are the most aggressive agents inducing chemical attack on the concrete.

The action of acids on the concrete specimen was the process of conversion of calcium compounds into the calcium salts and sulphuric acid which produces calcium sulphates in this research work. Due to the immersion of the concrete specimens in the acid solution small micro cracks were formed. The acid solution enters into the crack and it dissolves the readily available soluble calcium hydroxide and after evaporation it leaves calcium carbonate as white deposit on the surface of the concrete specimen.
The loss of weight due to acid attack of M25 grade of the conventional concrete is 2.41% after 28 days, 2.12% after 56 days, 1.98% after 90 days, 1.91% after 120 days and 1.80% after 180 days. The loss of weight due to acid attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 1.46% after 28 days, 1.31% after 56 days, 1.22% after 90 days, 1.17% after 120 days and 1.09% after 180 days.

It is observed that the loss of weight due to acid attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.95%, 0.81%, 0.76%, 0.74% and 0.71% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.11. The loss of weight of the concrete is due to the structure of the concrete that gets destroyed.

Figure 5.11 Loss of weight of M25 grade of concrete due to acid attack
The compressive strength of M25 grade of the conventional concrete is 21.82 MPa after 28 days, 22.40 MPa after 56 days, 23.64 MPa after 90 days, 23.91 MPa after 120 days and 24.01 MPa after 180 days. The compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 22.51 MPa after 28 days, 23.62 MPa after 56 days, 23.94 MPa after 90 days, 24.52 MPa after 120 days and 24.98 MPa after 180 days.

It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 3.16%, 5.45%, 1.27%, 2.55% and 4.04% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.12. The compressive strength of the concrete is significantly reduced because the acid attack completely converts the hardened cement paste destroying the entire pore system (Ghrici et al 2007).

![Figure 5.12 Variation of compressive strength with age of M25 grade of concrete due to acid attack](image)
The loss of weight due to acid attack of M30 grade of the conventional concrete is 2.20% after 28 days, 1.84% after 56 days, 1.81% after 90 days, 1.64% after 120 days and 1.51% after 180 days. The loss of weight due to chloride attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 1.23% after 28 days, 1.02% after 56 days, 0.98% after 90 days, 0.94% after 120 days and 0.90% after 180 days. The rate of loss of weight of the concrete specimen due to acid attack is high because it depends on the solubility of the calcium salts which is significantly high. Since the soluble salts were high, the reactions were more active (Fattuhi and Hughes 1986).

It is observed that the loss of weight due to acid attack of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 0.97%, 0.82%, 0.83%, 0.70% and 0.61% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.13.

![Figure 5.13 Loss of weight of M30 grade of concrete due to acid attack](image-url)
The compressive strength of M30 grade of the conventional concrete is 25.12 MPa after 28 days, 25.84 MPa after 56 days, 26.42 MPa after 90 days, 27.24 MPa after 120 days and 27.46 MPa after 180 days. The compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 28.41 MPa after 28 days, 29.12 MPa after 56 days, 30.04 MPa after 90 days, 30.46 MPa after 120 days and 30.92 MPa after 180 days.

It is observed that the compressive strength of the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 13.10%, 12.69%, 13.70%, 11.82% and 12.60% respectively higher than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.14. The Figure 5.15 shows the photograph of the compressive test of the concrete specimens subjected to the acid attack in progress.

![Figure 5.14 Variation of compressive strength with age of M30 grade of concrete due to acid attack](image-url)
Figure 5.15  Compressive strength of the concrete specimen subjected to acid attack in progress

It may be concluded that the above said admixtures in the prescribed proportion can be added during the preparation of the concrete and the structures constructed by using the above said concrete can be used for storing liquids which are harmful to concrete, industrial buildings or plants where the floor or wall may be damaged due to presence of chemicals or acids, damp conditions etc. It may be concluded that the acid attack is almost neutralized by the addition of the admixtures in the suitable proportions.

5.7  CORROSION STUDIES

Corrosion is defined as the destruction of materials due to chemical reaction with the environment and also the loss of steel (reinforcement bar embedded in the concrete) due to the formation of the rust. The corrosion of the steel reinforcement is the depassivation of steel with reduction in the concrete alkalinity through the process of carbonation. Most of the materials
undergo corrosion on exposure to natural environments or other artificial environments such as gases, liquids or moisture. The hazards to human life and economic losses occur due to premature deterioration and destruction of steel in buildings, bridges, culverts, pipes, marine and offshore structures, towers, water supply and sanitary fittings, electrical fittings etc (Santhakumar 2008).

The corrosion deteriorates the concrete structure because the product of corrosion i.e. ferric oxide which is brown in color occupies a greater volume than that of the steel and exerts substantial bursting stresses on the surrounding concrete. The outward manifestation of the rusting includes staining, cracking and spalling of the concrete. The progress of the process of the corrosion is generally in geometric progression with respect to the time. Subsequently the cross section of the reinforcement bar embedded in the concrete is significantly reduced. With the passage of time, the structural distress may occur either due to the loss of the bond between the steel and the concrete or due to the cracking and spalling of the concrete or as a result of the reduced steel cross sectional area (Santhakumar 2008).

A brown staining was observed on the concrete specimen. This brown staining was due to rusting or the corrosion of the steel permeating to the concrete surface. A cracking was also observed at the spot of brown staining. The loss of weight of the reinforcement bar in M25 grade of the conventional concrete is 5.84% after 28 days, 5.62% after 56 days, 5.23% after 90 days, 5.10% after 120 days and 4.91% after 180 days. The loss of weight of the reinforcement bar in the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 4.01% after 28 days, 3.92% after 56 days, 3.61% after 90 days, 3.20% after 120 days and 3.02% after 180 days.
It is observed that the loss of weight of the reinforcement in the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 1.83%, 1.70%, 1.62%, 1.90% and 1.89% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the Figure 5.16.

![Figure 5.16](image_url)

**Figure 5.16** Loss of weight of the steel embedded in the M25 grade of concrete due to corrosion

The loss of weight of the reinforcement bar in M30 grade of the conventional concrete is 5.64% after 28 days, 5.42% after 56 days, 5.12% after 90 days, 4.94% after 120 days and 4.88% after 180 days. The loss of weight of the reinforcement bar in the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 3.95% after 28 days, 3.80% after 56 days, 3.52% after 90 days, 3.10% after 120 days and 2.97% after 180 days.
It is observed that the loss of weight of the reinforcement in the concrete prepared by replacing 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash and 3.0% calcium nitrate is 1.69%, 1.62%, 1.60%, 1.84% and 6.31% respectively lower than that of the conventional concrete after 28 days, 56 days, 90 days, 120 days and 180 days of testing which are shown in the figure 5.17. It is also observed that the corrosion of the reinforcement decreases over the period of the time. It was consistently observed that corrosion was gradually decreasing and in long span of 2 to 3 years, the corrosion may be less than 1.0%. The corrosion which was observed during the experiment was due to several factors such as effect of pH, influence of oxygen, influence of moisture, influence of chloride ion concentration, thickness of concrete cover over the reinforcement bar and humidity. The figure 5.18 shows the photograph of corrosion test in progress for concrete cylindrical specimen.

Figure 5.17  Loss of weight of the steel embedded in the M30 grade of concrete due to corrosion
It may be concluded that by the addition of admixtures the corrosion of the steel in the concrete was considerably reduced. Saraswathy et al (2003) observed their study that there was a considerable reduction in loss of weight of reinforcement bar due the replacement of the cement with the admixtures. Hence it can be recommended that the admixture in the above said quantity can be used in the adverse and severe conditions of exposure.