EXPERIMENTAL INVESTIGATION AND PREDICTION OF COMPRESSIVE STRENGTH OF CONCRETE USING SOFT COMPUTING TECHNIQUES WITH DIFFERENT ADDITIVES

Submitted in partial fulfillment of the requirements

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Bachelor of Engineering

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CERTIFICATE

This is to certify that the project entitled **"Experimental Investigation And Prediction Of Compressive Strength Of Concrete Using Soft Computing Techniques With Different Additives"** is a bonafide work of **Ansari Shahbaz Akhtar Zaki Akhtar (11CE07), Khan Afroz Rahat Naeem (11CE22), Khan Mohd Haroon Mohd Nafis (11CE24), Khan Rahil Lodhi Hashmatullah (11CE26)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Bachelor of Engineering" in Department of Civil Engineering.

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Project Report Approval for B. E.

This project report entitled *"**Experimental Investigation And Prediction Of Compressive Strength Of Concrete Using Soft Computing Techniques With Different Additives**"* **by** ***Ansari Shahbaz Akhtar Zaki Akhtar** , **Khan Afroz Rahat Naeem** , **Khan Mohd Haroon Mohd Nafis** , **Khan Rahil Lodhi Hashmatullah*** is approved for the degree of "***Bachelor of Engineering***" in "***Department of Civil Engineering***".

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Declaration

We declare that this written submission represents my ideas in our own words and where others ideas or words have been included, We have adequately cited and referenced the original sources. We also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

High Performance Concrete (HPC) is the latest development in concrete, But HPC not only demands High cement consumption, which pushes the natural resources towards depletion, but also increases $C0_2$ emission on a higher extent. In the recent year's use of Supplementary Cementitious Materials (SCMs) is increased due to environment concerns, conservation of resource & economy because most of them are generally Industrial waste products such as fly ash, GGBS & micro silica. One of the costliest constituent of HPC is ultrafine material such as micro silica, alccofine. In recent years with the advancement in technology ultrafine fly ash is now being produced which is cheaper ultrafine material but, with less literature available on it. In available literature on Ternary blend concrete the level of replacement was restricted up to 30%-35%.

In this Experimental Investigation an attempt was made to investigate compressive strength (100MPa) of concrete by replacing Cement on 40%, 45%, 50%, by incorporating P100 fly ash as an ultrafine material and GGBS.

Each replacement was further divided into three sub parts (40%F.A-60%GGBS), (45%F.A-55%GGBS), (50%F.A-50%GGBS). Among which 40% replacement of cement (50%F.a-50%GGBS) gave maximum strength. Nominal mix was prepared with only OPC with w/c of 0.24.and all other ternary mixes was made on w/c of 0.2 to have an edge when compared with strength of nominal mix.

Nowadays, soft computing techniques are used to predict the properties of concrete and hence reduce the experimental work. Thus, a neural network also known as a parallel distributed processing network, is used as computing paradigm that is loosely modeled after structures of the brain. It consists of interconnected processing elements called nodes or neurons that work together to produce an output function.

This experimental investigation presents the application of Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) techniques for developing the model to predict the compressive strength of the concrete with SCMs. For this purpose, a systematic laboratory investigation was carried out. The compressive strength was evaluated on various mixes for 3 days, 7days, 14 days and 28 days of curing period. The data generated in the lab was used for development of the MLR and ANN model. The data used in the models are arranged in the format of four input parameters that cover the contents of OPC, FA, GGBS and w/c ratio respectively and one dependent variable as compressive strength of concrete for both MLR and ANN. Networks are trained and tested for various combinations input and output data sets.

Keywords: High Performance Concrete (HPC), Supplementary Cementitious Materials (SCMs), Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Artificial Neural Network (ANN), Multi Linear Regression (MLR).

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List of Nomenclatures/Abbreviations

OPC	Ordinary Portland Cement
SCMs	Supplementary Cementitious Materials
FA	Fly Ash
GGBS	Ground Granulated Blast Furnace Slag
HPC	High Performance Concrete
ANN	Artificial Neural Network
MLR	Multi Linear Regression
C-S-H	Calcium Silicate Hydrate
C-H	Calcium Hydrate
HSC	High Strength Concrete
HRWR	High Range Water Reducer
CTM	Compression Testing Machine
DLBD	Dry Loose Bulk Density

Chapter 1

Introduction

1.1 Sustainability and concrete industry

Sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". 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 (Aïtcin, 2000).

"Bearing in mind the technical advantages of incorporating PFA, slag, SF 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 PC, 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.

1.2 Environmental concern

It 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, depletion of natural resources etc.

Cement is the chief ingredient of concrete mixes and the most expensive one too. Besides that the production of 1 ton of cement emits 1 ton of CO_2. On an average 1.6 billion tons of cement is produced per year and hence emitting equal amount of CO_2 in the atmosphere. It is predicted that the consumption of cement is going to double in every decade. This pressure of ecological constraints and environment regulation are bound to increase in the coming years which will lead to greater use of Supplementary Cementitious Materials (SCMs).

Cement industry is one of the primary producers of carbon dioxide, a major greenhouse gas. the major component of concrete is cement, one reason why the carbon emissions are so high is because cement has to be heated to very high temperatures in order to form.

For any developing country, power generation being the engine of growth, including India. The power generation in India has increased from 1362 MW in 1947 to 120,000 MW during 2004-05. Further Government of India has successfully achieved the goal of 200,000 MW by 2012, and has planned for enhancement capacity of installed capacity to 3000,000 MW by 2017. Coal being abundantly available has been major source of energy till date and expected to remain in near future as well. Indian coal, though deficient in sculpture, contains higher amount of ash (about 35% to 40%), hence generation of huge quantity of fly ash in India. The annual generation of ash has increased from 1.0 million tons in 1947 to about 40 million tons in 1994 and 112 tons during 2005. As per the estimation of Fly Ash Utilization Programme (FAUP) the annual figure of fly ash generation is expected to 225 million tons by 2017. The residue, commonly called fly ash, that is being produced annually from different thermal power plant is mainly 80% in the form of fly ash and balanced 20% in the form of bottom ash. This needs thousands of hectares of precious land for its disposal causing severe health and environment hazards also. The environmentally acceptable disposal of this material has become an increasing concern.

1.3 Utilization of Supplementary Cementitious Materials

1.3.1 Fly ash

Fly ash is the ash precipitated electro-statically from the exhaust fumes of coal fired power station. In India nearly 70 million tons of fly ash is being produced every year while a very small quantity is used in manufacturing of cement. It is an eco-friendly product. The fly ash particles are spherical and are generally of higher fineness than cement so that the silica is readily available for reaction. As per IS 3812: 1981, the percentage of silica and alumina should be minimum 70% and maximum loss on ignition 12 %. Much superior quality fly ash is available from thermal power plants than specified in IS code.

P100 fly ash: Though the most convenient method to reduce the particle size of any material is to grind it. This is not the most viable option in the case of fly ash, as by grinding the fly ash particles lose their perfect spherical shape and thereby the advantage of improving the workability of concrete by using fly ash is lost. Thus, Dirk India Pvt. Ltd. (DIPL) decided to process coarse raw fly ash by means of mechanical air classifiers which segregates the coarser fraction of fly ash from the finer ones, without altering the chemistry of fly ash and disturbing the shape of particles. These classified fly ash products are marketed to the construction industry in India and overseas under the brand name of Pozzocrete.

1.3.2 GGBS

Ground-granulated blast-furnace slag (GGBS or GGBFS) obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that dried and ground into a fine powder.

The chemical composition of a slag varies considerably depending on the composition of raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the blast furnace the slag floats on the top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 ^{o}C in order to prevent the crystallization of merwinite and melitite.

1.4 Historical Development

The use of SCM‟s was done from the ancient Greeks who incorporated volcanic ash with hydraulic lime to create a cementitious mortar. The Greeks passed this knowledge on to the Romans, who constructed such engineering marvels as the Roman aqueducts and the Coliseum, which still stand today. Early SCMs consisted of natural, readily available materials such as volcanic ash. Nowadays, most concrete mixture contains supplementary cementitious material that forms part of the cementitious component.

The journey of fly ash in construction industry is summarized in the Table 1.1.

Table 1.1: Sixty-Five Years of Developing fly Ash

As a fully Recognized Component of Cement 1935: First recognized use of fly ash in concrete construction.
1965: BS 3892. Fly ash considered as fine aggregate, broad material range.
1977: Fly ash awarded British BBA certificate for use as cement component.
1982: BS 3892, Part 1. Fly ash as a cement component, only finest materials permitted.
1987: CEN Committee set up to develop unified European fly ash standard.
1995: BS EN 450, publication of European Standard for fly ash.
2000: BS EN 197-1, Cement (first time including fly ash and other materials).

GGBS as a binder can be used in different ways. Blended cements of GGBS and ordinary Portland cement (OPC) have been used for more than 100 years and are covered by international standards (ASTM-C595 2008). The combination of GGBS with OPC and pozzolans is reported by the American Concrete Institute committee 233 (ACI-233 2003). GGBS-alkali activated binder systems are used extensively in Eastern Europe, and the activation of slags with sulphate minerals have been used for more than 50 years in Europe.

1.5 Binary Mixes

First approach adopted was to replace cement with one SCM's which was called as Binary Mix, with fly ash, Ground Granulated Blast Furnace Slag (GGBS), Micro silica, rise husk fly ash (RHA) etc., solely. The reduction in cost is associated with the fact that most supplementary cementitious materials are by-products.

For fly ash optimum replacement was found to be 20%-35% [Alvin Harison, et.al, Aman Jatale, et.al] above this replacement for fly ash a considerable reduction in compressive strength of concrete was found. Literature indicates that GGBS replacement levels of between 20% - 40% (S.Arivalagan) were often adopted to give the optimal strength performance. For resistance to sulphate attack and lower heat of hydration at early age, the replacement levels used were often from 60% to 85% for mass concrete construction.

Increase in strength of concrete, incorporated with SCM's is attributed to the Formation of excess C-S-H gel formation, which are produced due to secondary hydration. When siliceous compound of SCM's reacts with the present C-H gel, which is formed due to primary Hydration. The C-H gel is converted into C-S-H which impart strength to concrete (L. O. Ettu, et.al). The presence of excess calcium hydroxide decreases the durability of concrete as calcium. .hydroxide reacts with the sulphates present in soils or water to form calcium sulphate which further reacts with C_3A and cause deterioration of concrete (M.S. Shetty 2005).

Durability of concrete is increased while using SCM's (A.K Mullick) since industrial wastes are relatively lesser-known materials than cement, it is possible to have questions on their long term effects on concrete. Doubts about effects of fly ash and granulated slag on durability of concrete had initially inhibited their full use in structural concrete. However, experience over the years and continuous research has actually revealed positive effects on durability. Corrosion of reinforcement, sulphate attack, heat of hydration and alkali silica reaction (ASR) in concrete are the major issues of durability. Use of fly ash, granulated slag or silica fume is known to be beneficial in all such cases. These are supported by well – documented case studies and performance records reported from foreign sources.

With every SCM there was demerits associated with it, for example fly ash increase the workability of concrete, but one of the greatest drawbacks while using fly ash as pozzolanic material in concrete is the early age performance of concrete (D.Audinarayana, et.al.), to overcome the demerit of one SCM's another SCM's was introduced to the concrete mix which led to the emergence of ternary blend concrete.

1.6 Ternary Mix Concrete

Ternary mixtures are becoming more prevalent because they can enhance performance and reduce costs. The reduction in cost is associated with the fact that most supplementary cementitious materials are by-products. However, the use of these materials also decreases the amount of Portland cement that must be manufactured. This makes the cement industry more sustainable.

The fly ash replacement in binary cements generally reduced the water requirement, while slag replacements for OPC appeared to increase the water requirement for a given consistency. These results imply that fly ash can function as a water-reducing agent in concrete, thereby improving concrete flow ability, but GGBFS will not function this way. As a result, if slag and fly ash are used together, such ternary cement concrete may have the same flow ability as OPC concrete. (Iowa State University, Civil Department Final Report on Evaluating Properties of Blended Cements for Concrete Pavements. Dec2003). With the advance in Plasticizers produced, high range water reducers was available in late 1980. While incorporating High range water reducers with ternary blend concrete leaded to the emergence of High Performance Concrete.

1.7 High Performance Concrete

The HPC is concrete which ensures long-time durability in structures exposed to aggressive environments. Durability of concrete is its ability to resist weathering action, chemical attack, abrasion and all other processes.

Weathering includes environmental effects such as exposure to cycles of wetting and drying, heating and cooling, as also freezing and thawing. Chemical deterioration process includes acid attack, expansive chemical attack due to sulphate reaction, alkali aggregate reaction, corrosion of steel in concrete due to moisture and chloride ingress (Ambuja Technical Literature Series).

HPC is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices (Aitcin).

The concept of HPC has definitely evolved with time. Initially it was equated to high strength concrete (HSC), which certainly has some merit, but it does not show a complete and true picture. Other properties of the concrete must also be considered, and may even take priority over the strength criterion.

Use of supplementary cementitious materials (SCMs) is necessary for producing HPC. Concretes with these cementitious materials are used extensively throughout the world. In

HPC, materials and admixtures are precisely selected and optimized to form higher strengths (early as well as ultimate) and higher durability as compared to normal concrete. HPC is also called "durable" concrete because its strength and impermeability to chloride penetration improves the service life as compared with that of conventional PCC. Some of the major users of HPCs are power, gas, oil and nuclear industries. The applications of such concretes are increasing with the passage of time due to their enhanced structural performance, environment friendliness and low bearing on energy utilization (Ayub Elahi).

1.8 Statement of the Problem

Significant amount of work was done on ternary mix concrete, in which cement was replaced with Fly ash, GGBS, Micro silica, Alccofine, Rice Husk Ash etc. (Jay D Patel & AJ Sheth, D.Audinarayana, et.al, Deval Soni, et.al, R.Manju & Dr.J.Premalatha, L. O. Ettu, et.al, Hariharan A R, et.al, etc.) In ternary mix concrete the level of replacement of cement with SCM's was restricted to 35%-40%, no literature was available that has replaced more than 40% cement with SCM's.

Moreover micro silica was used as ultra-fine material to achieve optimum packing density. This is the costliest material in ternary mix concrete, it also retard workability appreciably and increases the dosage of super plasticizer. A new ultra-fine material was introduced in recent times named P100 fly ash which was nearly of the same size as micro silica, but very few literatures and experimental data was available on it.

1.9 Aim and Objectives of the Research

The primary aim of this investigation was to evaluate the influence of high volumes of SCMs on the properties of HPC. More specifically, the research had the following objectives:

1. To achieve higher replacement of cement with SCMs at 40%, 45% and 50% and study its significance on compressive strength of concrete.
2. To investigate the effects of various replacement levels of FA and GGBS on compressive strength of concrete.
3. To produce more economical, eco-friendly and sustainable concrete.
4. To enhance the life of structure in severe environment.
5. To predict the Compressive strength of HPC at different levels of replacements using Soft Computing Techniques.

1.10 Scope of the Project

In view of the aforementioned problem as specified previously, following scope is outlined in respect of the present investigation.

I. To replace cement on a higher percentage level in ternary mix concrete.
II. To investigate the compressive strength of concrete on replacement of cement with P100 fly ash and GGBS.
III. To investigate the effects of P100 fly ash as ultra-fine material in ternary mix concrete.

Chapter 2

Review of Literature

2.1 Introduction

A review of literature revealed that various laboratory investigations have been conducted on the replacement of cement in concrete with different additives. Many investigations used fly ash, ground granulated blast furnace slag, micro silica, rice husk ash, metakaolin, etc.

Pursuant to a quick glance through a literature review given in the first chapter, a detail account of the corresponding literature in the context of different materials is given in this chapter.

2.2 Supplementary Cementing Materials

Fly ash, silica fume, or slag are often mandatory in the production of high-strength concrete; the strength gain obtained with these supplementary cementing materials cannot be attained by using additional cement alone economically. These supplementary cementing materials are usually added at dosage rates of 5% to 20% or higher by mass of cementing material. Some specifications only permit use of up to 10% silica fume, unless evidence is available indicating that concrete produced with a larger dosage rate will have satisfactory strength, durability, and volume stability. The water-to-cementing materials ratio should be adjusted so that equal workability becomes the basis of comparison between trial mixtures. For each set of materials, there will be an optimum cement-plus-supplementary cementing materials content at which strength does not continue to increase with greater amounts and the mixture becomes too sticky to handle properly. Blended cements containing fly ash, silica fume, slag or calcined clay can be used to make high-strength concrete with or without the addition of supplementary cementing materials.(*Chapter 17 _ High-Performance Concrete*).

The effects of SCMs on the pore structure and chloride permeability of concrete was examined by both Geiker et al. (1991) and Torii and Kawamura (1991). Using the AASHTO T 277 method, they found that the concrete with SCMs was much less permeable to chloride ions than the concrete without these materials regardless of curing and environmental conditions. Torii and Kawamura also found that at the surface of concretes with a SCM, the hydration of OPC was considerably low and coarse pores were developed when concrete with a SCM were stored in a dry condition for a long time.

2.3 Binary Mix

2.3.1 Binary Mix with Pulverized Fly Ash

In this study, use of Ultra-fine (Pozzocrete P100) fly ash was done to make concrete mixes.

The concrete mixes made with Pozzocrete 100 were found to be more cohesive and easy to work with compared to all the corresponding mixes made with the use of Portland clinker alone or using micro silica fume which were tending to be harsh as well as sticky, suggesting that though considerably less finer than micro silica fume, Pozzocrete P100 has better particle size and distribution for enabling concrete to have the desired flow characteristics. This is thought to be a big plus for Pozzocrete P100. The water permeability and RCPT test results for all the concrete mixes made with Pozzocrete P100 were essentially similar to the corresponding concrete mixes made with micro silica fume. (George Dirk, Dirk Group of Companies India).

According to Xiuping Feng and Boyd Clark (2010) fly ash is by product of combustion of pulverized coal in electric power generating plants. It is the most widely used supplementary cementitious material in concrete. It is used in more than 50% of ready mix concrete. The replacement level of Class F fly ash is often at 15-20% by mass of cementitious material, and it is between 15-40% by mass of cementitious material for Class C fly ash. The properties of fly ash can greatly affect the properties for both fresh and hardened concrete. Similar type of work is done by Richard A. Livingstone and Walairat Bumrongjaroen (2005), Karthik H. Obla (2008), Osman Gencel et.al (2012), Asma Y. Shebani & Peter Claisse (2011), etc.

Alvin Harison, et.al (2014) concluded that compressive strength of fly ash concrete up to 30% replacement level is more or equal to referral concrete at 28 and 56 days. It was observed that at 28 and 56 days in 20% replacement of PPC by fly ash, the strength marginally increased from 1.9% to 3.28%. It was also observed that up to 30% replacement of PPC by fly ash, the strength is almost equal to referral concrete at 56 days. One of the greatest drawbacks while using Fly ash or other pozzolanic material in concrete is low early strength.

Jay D Patel and AJ Sheth (2014) reported that fly ash improves the performance and quality of concrete. Fly ash affects the plastic properties of concrete by improve workability; reduce water demand and reducing heat of hydration. Due to spherical shape of particles, it can also increase workability of cement while reducing water demand.

Similar work was done by Aman Jatale, et.al (2013) in which he researched out that use of fly ash improves the workability of concrete. This phenomenon can be used either the unit water content of mix or to reduce the admixture dosage. Density and air content of concrete mix are generally unaffected with the use of fly ash. Bleeding in fly ash concrete is significantly reduced and other properties like cohesiveness, pumping characteristics and surface finish are improved.

Again Jay D Patel and AJ Sheth (2014) reports that fly ash possesses very less to no cementitious properties, but in presence of moisture it reacts with calcium hydroxide to form Calcium silicate hydrate (CSH) which adds to the strength.

It has been suggested by (Bakker, 1983) that the presence of FA results in a greater precipitation of cement gel products rather than occurs witrh OPC alone, more effectively blocking pores and thus also helping to reduce permeability. Furthermore, considering the effect of pozzolanic reaction, it is worth noting that FA, by combining with $Ca(OH)_2$ released from the hydration of OPC, will consume the amount of $Ca(OH)_2$ that can be leached and thus further reduction in the permeability of concrete. However, the use of FA in concrete can effectively reduce its permeability in the final analysis would depend on the proportioning of the binder, i.e., the relative amounts of OPC and FA, the rate of concrete and its curing regime.

Use of fine and superfine fly ash (SFFA) will help to produce high strength concrete by improving the quality of cement paste matrix, with fly ash helping to achieve the desired particle packing and denser paste structure, and at the same time, for a given consistence, allowing water content to be reduced, which in turn (unlike microsilica fume) reduces water/cement ratio of the mix. (George Dirk, Dirk Group of Companies India).

2.3.2 Binary Mix with GGBS

Hamling (1992) reviewed that GGBS concrete has lower early strengths because the rate of initial reaction of GGBS is slower than that of Portland cement. GGBS is therefore generally grounded to a finer state than Portland cement. Researcher reported that, as the fineness of GGBS increased from around 4000 cm2/g to 6000 cm2/g, the 28-day strength increased significantly

Lane & Ozyildirum (1999) reported that the early strengths (up to 28 days) of concrete mixes (with 25%, 35%, 50%, and 60% GGBS replacements) were lower than that of Portland cement concrete mixes. By 56 days, the strength of 50% and 60% GGBS mixes exceeded that of the Portland cement mix, and by one year all GGBS mixes were stronger than the Portland cement mixes.

Sonali K. Gadpalliwar, et.al (2014) partially replaced cement with GGBS by 10%, 20% and 30% and came to a result that By adopting same critical mix and replacing cement by GGBS, it is found that by increasing the percentage of GGBS; workability increases but strength decreases.

GGBS concrete generally has a low permeability resulting in reduced chloride penetration, enhanced resistance to sulphate attack and alkali silica reaction as compared with ordinary Portland cement concrete. Ground granulated blast furnace slag has lower heat of hydration, hence generates less heat during concrete production and curing. As a result, GGBS is a desirable material to utilize in mass concrete placements where control of temperatures is an issue. Percentage replacements by weight of GGBS for cement have ranged from 10 to 90%. One of the greatest drawbacks while using Fly ash or other pozzolanic material in concrete is early strength. Bleeding is also a serious problem associated with GGBS, At higher replacement levels, bleeding rates may be higher. The formation of scum layer on the top of specimens is been observed on higher dosage of GGBS.

Collepardi *et al*., (2004) found that the inclusion of GGBS in concrete at any level above 15% replacement of OPC resulted in an increase in the rate of carbonation. At the 15% level it had similar carbonation rates to pure OPC concretes. A possible reason for this was offered by Ngala and Page (1997), who found that there was significant increase in the proportion of large capillary pores (>30nm) after carbonation was used at 65% replacement level for OPC. The control mix of pure OPC had only a slight increase in the proportion of large pores. De Ceukelaire *et al.*, (1993) found that the use of GGBS resulted in the formation of a concrete with higher porosity than that of a pure OPC concrete. He attributed this to the presence of less $Ca(OH)_2$ and more C-S-H in the GGBS hardened cement paste than in OPC. The carbonation of C-S-H produces less expansive compounds than $Ca(OH)_2$ and thus will have less effect at reducing porosity.

2.4 Ternary Mix

Jay D Patel and AJ Sheth (2014) An optimum level was set for all the SCMs in binary concrete mixes, at which there would not be any unwanted change in fresh as well as hardened properties of concrete, above this optimum level result showed insignificant change in properties of concrete. But there was further more scope for replacement of cement in concrete, by replacing it by more than one ingredient which led to the emergence of ternary and quaternary concrete.

According to D.Audinarayana, et.al (2013) the early age strength development of fly ash blended binary concretes shows poor performance than the ordinary concrete. Researchers all over the world are developing Ternary Blended Concretes by adding a superfine mineral admixture like Micro Silica to the binary blended concretes of fly ash. Micro Silica in the ternary blend improves the early age performance of concrete and fly ash improves the properties at the later age.

Sonali K. Gadpalliwar, et.al (2014) divided their research paper in three phase, at first phase 0%, 15%, 30%, 45%, 60%, 75%, 90% and 100% of quarry sand was replace with natural sand , optimum percentage of replacement at which maximum compressive strength is achieved. It was observed that when natural sand is partially replaced with 60% quarry sand maximum strength is achieved. In second phase, cement is partially replaced with GGBS by 10%, 20% and 30%. In third phase, combination of GGBS and RHA is partially replaced with cement. The composition of 22.5% GGBS + 7.5% RHA with 60% of quarry sand gave good strength result. Another factor which got incorporated due to addition of one or more additive was high performance concrete.

Concrete produced with a combination of fly ash, slag, and Portland cement has been proven to enhance concrete performance by producing higher long-term strengths, improving workability while requiring less water, and reducing efflorescence and permeability. Fly ash has been used to replace in excess of 35% of the cement in concrete, and slag has been used to replace in excess of 50% of the cement in similar applications. In reality, cement is typically replaced by fly ash at 15% to 25%, and by slag at 40%. Coincidentally, in many markets, the combined cost for cement and 20% fly ash is equivalent to a mix with cement and 40% slag. At greater rates of cement replacement for either material, the early strength and setting for flat work can be delayed, and in some cases, the 28 day design strength may have to be extended to 56 days or more. In either case, construction needs and schedules will impact the cement replacement percentage. By combining the reactivity, workability and water reduction of the lower priced fly ash with the reactivity of slag that allows for greater Portland cement replacement, more economical, high quality concrete can be produced. The typical percentages for both fly ash and slag are around 15% to 17%, for a combined replacement of cement of 30% to 35%. (HEADWATER Resources).

2.5 Packing Density of Aggregates

Jeenu G., et.al (2012) reported that aggregates with higher packing density generally produced concretes with higher compressive strength. Further, for mixes with marginal variation in packing density of aggregates, the one having higher coarser fraction (>4.75mm), in all cases, yielded higher values of compressive strength.

Aggregate characteristics as well as properties of cement paste and interfacial transition zone (ITZ) govern the strength and durability of concrete. With the improvement in properties of cement matrix and ITZ by the use of mineral and chemical admixtures in high performance concrete (HPC), aggregate skeleton has become the weakest phase (Meddah et al.,2010). About

65 to 75 percentage of the bulk volume of HPC is occupied by aggregates (e.g. Jamkar and Rao, 2004). Aggregate characteristics such as density and uniformity of aggregate packing and the corresponding particle size distribution have been found to play a paramount role in strength and behaviour of these concretes (Meddah et al., 2010). Aggregate packing has significant effect on the rheological properties of concrete mixes also. Dense particle packing improves workability and compactability of concrete and reduces paste consumption, thereby providing significant cost savings as well (Sobolev and Amirjanov, 2010). Models for

predicting concrete compressive strength also base their validation on producing concrete mixtures of optimum packing density (Lecomte et al., 2005). An in-depth understanding of the packing of aggregates in concrete is, therefore, essential in optimising the mix composition.

2.6 High Performance Concrete

The HPC is concrete which ensures long-time durability in structures exposed to aggressive environments. Durability of concrete is its ability to resist weathering action, chemical attack, abrasion and all other deterioration processes. (A to Z answers on high performance concrete, 2003).

In general, a "High performance Concrete" can be defined as that concrete which has the highest durability for any given strength class, and comparison between the concretes of different strength classes is not appropriate. This means that, with the available knowledge, one can always strive to achieve a better (most durable) concrete required for a particular application.

High performance concrete (HPC) is a specialized series of concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices. In the other words a high performance concrete is a concrete in which certain characteristics are developed for a particular application and environment, so that it will give excellent performance in the structure in which it will be placed, in the environment to which it will be exposed, and with the loads to which it will be subjected during its design life. (Dr. R. B. Khadiranaikar)

The concept of HPC has definitely evolved with time. Initially it was equated to high strength concrete (HSC), which certainly has some merit, but it does not show a complete and true picture. Other properties of the concrete must also be considered, and may even take priority over the strength criterion. (Ayub Elahi 2009).

Study by S.C. Maiti, et.al (2006) indicates that in very high-strength concrete (compressive strength >80 MPa), Abram's water-cement ratio 'law' is not valid strictly, because the water-cementitious material ratios are very low. The role of water-cement ratio is not prominent in such concretes. These high-strength concretes had w/c ratios in the range of 0.25 to 0.33. The water-cementitious material ratios versus 28-day compressive strength of concrete indicates that there exists a continuum of the relationship between the two parameters in the range indicated. It is noteworthy that such concretes contain about 30 to 40 percent of mixing water compared to normal strength concrete without high range water reducing admixture. By using a polycarboxylate based superplasticiser the water content in the case of high strength concrete is reduced to about 130 to 140 lit/m3of concrete.

HPC is usually achieved by using very low water - binder ratios (w/b). Indeed, in a recent publication (Aitcin, 1998) the author defined HPC as essentially all concrete having a water-binder ratio not more than 0.40. Only in more recent times, recognition has been given to the fact that ‘high-strength’ concrete commonly offers other improvements in performance, such as higher flow ability, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance and better durability (Aitcin, 1998). In spite of this, the term HPC continues to be used primarily for concrete suitable for high-strength application when one is looking for performance in terms of strength only.

For normal strength concrete, the cement contents are typically in the range of 300- 450 kg/m3 of concretes, whereas for very high-strength concrete, the content of cementitious materials (cement + silica fume + fly ash / blast furnace slag) is in the range of 500 to 650 kg/m3 of concrete.

According to Traian Onet, (2006) Keeping concrete competitive with construction materials encouraged the achievement of new high performance and implicitly, high strength and ultrahigh strength concrete. The need for tall buildings and the construction of highway program from Romania made high performance concrete with remarkable physical, chemical and mechanical characteristics to be used.

In high-strength concrete, careful attention must be given to aggregate size, shape, surface texture, mineralogy, and cleanness. For each source of aggregate and concrete strength level there is an optimum-size aggregate that will yield the most compressive strength per unit of cement. To find the optimum size, trial batches should be made with 19 mm (3⁄4 in.) and smaller coarse aggregates and varying cement contents. Many studies have found that 9.5 mm to 12.5 mm (3⁄8 in. to 1⁄2 in.) nominal maximum-size aggregates give optimum strength. In high strength concretes, the strength of the aggregate itself and the bond or adhesion between the paste and aggregate become important factors. Tests have shown that crushed-stone aggregates produce higher compressive strength in concrete than gravel aggregate using the same size aggregate and the same cementing materials content; this is probably due to a superior aggregate-to-paste bond when using rough, angular, crushed material. For specified concrete strengths of 70 MPa (10,000 psi) or higher, the potential of the aggregates to meet design requirements must be established prior to use. (*Chapter 17 _ High-Performance Concrete*).

HPC also provides enhanced mechanical properties (in terms of tensile and compressive strength) in precast industry in addition to strong stiffness. The advantages of HPC cannot be denied in cold areas where durability performance of concrete can resist penetration of chloride present in snow and water. This results in longer life for the embedded reinforcing steel and a reduction in the deterioration processes (Kuennen, 2004).

2.6.1 Material combination used for HPC

It is compulsory to get the maximum output of all of the materials involved in producing HPC. In many cases, however, concrete is classified as having 'high performance' exclusively because its strength is much greater than that of typically specified concrete. HPC is usually achieved by using very low water - binder ratios (w/b). Indeed, in a recent publication (Aitcin, 1998) the author defined HPC as essentially all concrete having a water - binder ratio not more than 0.40. Only in more recent times, recognition has been given to the fact that 'high-strength' concrete commonly offers other improvements in performance, such as higher flowability, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance and better durability (Aitcin, 1998). In spite of this, the term HPC continues to be used primarily for concrete suitable for high-strength application when one is looking for performance in terms of strength only.

Various materials used for making HPC are discussed separately below. However, it must be remembered that prediction with any certainty regarding the behaviour of each ingredient when combined in a concrete mixture is not realistic. Any material incompatibilities will be highly detrimental to the finished product. Thus, the result of any mix design process must be the extensive testing of trial mixes. HPC will normally contain not only OPC, aggregate and water, but also superplasticisers and SCMs. It is possible to achieve compressive strengths up to 98 MPa using FA or GGBS as the SCMs. (Mindess, 1994).

2.7 Super-plasticizers

In recent times, it is essentially impossible to make HPC (inclusive of HSC) at adequate workability in the field without the use of superplasticiser. Unfortunately, different superplasticiser will behave quite differently with different cements (even cements of nominally the same type). This is because of the variability in the minor components of the cement (which are not generally specified), and in part to the fact that the acceptance standards for superplasticisers themselves are not very tightly written. Thus, some cements will simply be found to be incompatible with certain superplasticisers. (Ayub Elahi 2009).

Currently six different types of superplasticiser are used (Bradly and Howarth, 1986; Rixom and Mailvaganam, 1999 and Ramachandran and Malhotra, 1998).

- Lignosulfonates
- Poly melamine
- Poly naphthalene
- Carboxylates
- Polyacrylates
- Based on polyphosphonates and different copolymers

Until recently, Poly melamine and poly naphthalene were the principal source of commercial superplasticisers, but recently caboxylates are used extensively in spite of their high price (Aïtcin, 2008).

According to Dr. R. B. Khadiranaikar the superplasticisers are extensively used in HPCs with very low water-cementitious material ratios. In addition to deflocculation of cement grains and increase in the fluidity, the other phenomena that are likely to be present are the following.

(a) Induced electrostatic repulsion between particles.

(b) Dispersion of cement grains and consequent release of water trapped within cement flocks.

(c) Reduction of surface tension of water.

(d) Development of lubrication film between particles.

2.7.1 Superplasticiser dosage

There is no specific way of determining the required superplasticiser dosage. It must be determined after carrying out some sort of trial and error procedure. For the development of high strength, one should work with the lowest w/c possible, and thus the highest superplasticiser dosage rate. For high strength concrete, the dosage of the superplasticiser is kept normally 5 to 15 litres per cubic metre of concrete, depending on the solids content in the superplasticiser and its nature. Such a dosage allows a reduction in water content of about 45 to 75 kg/m3 of concrete (Aitcin and Neville, 1993). This is because HPC mix must be sufficiently workable for the solids to be dispersed in such a manner that dense packing is achieved, which requires deflocculation of cement particles. This is achieved by the use of a superplasticiser at a large dosage.

2.8 Soft Computing Techniques

2.8.1 Artificial Neural Network (ANN)

Artificial neural networks are made up of interconnecting artificial neurons (usually simplified neurons) designed to model (or mimic) some properties of biological neural networks. Artificial neural networks can be used to model the modes of operation of biological neural networks, whereas cognitive models are theoretical models that mimic cognitive brain functions without necessarily using neural networks while artificial intelligence are well-crafted algorithm that solve specific intelligent problems (such as chess playing, pattern recognition, etc.) without using neural network as the computational architecture. (Abdul Raheman, Prof. P. O. Modani, 2013).

ANN is essentially a group of interconnected computing elements, or neurons that has certain performance characteristics resembling biological neural networks of the human brain (Haykin, 1999).

They are computing systems made up of a number of simple, highly interconnected processing elements, which processes information by their dynamic state response to external inputs. The fundamental concept of neural networks is the structure of the information processing system (Ripley, 1996).

Generally, an ANN are made of an input layer of neurons, sometimes referred to as nodes or processing units, one or several hidden layer of neurons and output layer of neurons. The neighboring layers are fully interconnected by weight. The input layer neurons receive information from the outside environment and transmit them to the neurons of the hidden layer without performing any calculation (Rao and Datta, 2007; 2009).

Layers between the input and output layers are called hidden layers and may contain a large number of hidden processing units (Matsuura and Willmott, 2005).

All problems, which can be solved by a perceptron can be solved with only one hidden layer, but it is sometimes more efficient to use two or three hidden layers. Finally, the output layer neurons produce the network predictions to the outside world. Each neuron of a layer other than the input layer computes first a linear combination of the outputs of the neurons of the previous layer, plus a bias. The coefficients of the linear combinations plus the biases are called weights. Neurons in the hidden layer then compute a nonlinear function of their input. Generally, the nonlinear function is the sigmoid function (Ripley, 1996).

2.8.2 Multiple Regression Analysis

MLR is the simplest and well developed representation of a casual, time invariant relationship between an input function of time and corresponding output function. MLR models are considered as benchmark for comparison with other techniques in reservoir inflow forecasting (Chau *et al* 2005). MLR attempts to model the relationship between
two or more independent variables and dependent variables by fitting a linear regression equation to observed data.

Every value of the independent variable 'x' is associated with a value of the dependent variable 'y'. If y is a dependent variable (expected value) and $x1, x2, . . . , xn$ are independent variables, then the basic MLR model is given by $y = a + b1x1 + b2x2 + \cdots + bnxn$ where a, bi = regression constant determined using a least square method.

The SPSS (Version 16) software was used for performing the regression analysis. In the multiple regression analysis, various formulae are developed by varying the input parameters to predict the strength of such stabilized mixes corresponding to 3 days, 7 days, 14 days and 28 days' curing. Selection of equations with different inputs, which would help the user to predict the compressive strength of such mixes with available data/input parameters.

Chapter 3

Materials and Methodology

3.1 General

The present study envisages the performance of high strength concrete on replacement of cement. This chapter gives detail account of the various materials used in present study along with its physical, chemical and other allied properties/ characteristics. It also gives the details of various experimental programmes that are conducted in the present study.

3.2 Materials

In view of the proposed experimental study, the materials such as Fly Ash, GGBS, Superplasticizers, Ordinary Portland Cement, Aggregates (Metal 10, Metal 20) and Crushed Sand were used.

3.2.1 Binder Materials

3.2.1.1 Fly ash

The fly ash was procured from *Ambuja Cement Limited, Andheri*, which in turn, was supplied by *Dirk India Private Limited, Eklahare Nasik*. The fly ash used in the investigation is Ultra-fine (Pozzocrete P100) fly ash. The chemical composition and physical properties of the Ultra-fine fly ash as supplied by the suppliers are shown in Table 3.1.

3.2.1.2 GGBS

The GGBS was procured from *JSW Steel Pvt. Ltd.* The chemical composition and physical properties of the GGBS as supplied by the suppliers are shown in Table 3.2.

3.2.1.3 Ordinary Portland Cement

The cement used in the said investigation comprised of Ordinary Portland Cement (Ultratech Cement of 53 Grade) which was made available by local supplier from panvel. The chemical composition and physical properties of the GGBS as supplied by the suppliers are shown in Table 3.3.

3.2.2 Superplasticizers

The superplasticiser used, namely Master Glenium SKY8880, was procured from BASF Pvt. Ltd. Turbhe. The superplasticiser used is Polycarboxylic based High Range Water Reducer (HRWR) Admixture.

3.2.3 Aggregates

3.2.3.1 Coarse Aggregates

Coarse aggregates of 20 mm and 10 mm nominal size having specific gravity 2.79 confirming to IS 383:1970 was used in this investigation.

3.2.3.2 Fine Aggregates

Crushed sand of zone-II having specific gravity 2.74 confirming to IS 383:1970 was used in this investigation.

Table 3.1: Physical properties and Chemical composition of Ultra-fine fly ash

Chemical composition	
Constituents	**Weight %**
Silicon dioxide (SiO_2)	50
Calcium oxide (CaO)	5.5
Magnesium oxide (MgO)	4.5
Sodium oxide (Na_2O)	2
Sulphur oxide (SO_3)	1.5
Physical properties	
Presentation	Finely divided dry powder
Colour	Greyish White
Bulk Weight	0.65 tonne/ m3
Specific Density	2.3
Loss of Ignition	<2.5 %
Particle Size	Zero retention on 45 micron sieve, <0.25 % retained on 25 micron sieve
Particle Shape	Spherical

Table 3.2: Chemical composition of GGBS

Constituents	**Weight % GGBS**
CaO	30-45
SiO_2	30-38
Al_2O_3	15-25
Fe_2O_3	0.5-25
MgO	4-17
Glass	85-98
Specific gravity	2.9

Table 3.3: Characteristics of Cement

Normal Consistency (IS:4031 Part IV)	
Required Water for Normal Consistency	110ml
% of Normal Consistency	27.5%
Setting Time (IS:4031 Part V)	
Initial setting Time	150 Min (Maximum 30 Min)
Final Setting Time	225 Min (Maximum 600 Min)
Specific Gravity (IS:4031 Part II)	3.14
Specific Surface (Fineness) (IS:4031 Part II)	310.83 (Maximum 225 cm^2/gm)
Compressive Strength	
3 Days	27 MPa
7 Days	37 MPa
28 Days	53 MPa

3.3 Experimental Programme

The present study involves a series of various tests performed on various materials to arrive upon certain physical properties wherever required and if not given along with the prominent tests to evaluate the strength parameters. The various tests that were conducted during the present study include:

i. Determination of specific gravity of aggregates and crushed sand.
ii. Determination of water absorption of aggregates and crushed sand.
iii. Determination of Compressive strength of concrete.

3.4 Methodology

Concrete mixes of grade M100 was made using OPC. Replacement of cement was made using Supplementary Cementitious Materials, namely Fly ash and GGBS at 40%, 45% and

50%. These replacement were further divided into ratios of (40:60), (45:55) and (50:50) for Fly ash and GGBS respectively.

The concrete mixes were tested for compressive strength at 3 days, 7 days, 14 days and 28 days of curing.

Following section describes the experimental programme and the procedures used for conducting various tests involved in the programme.

3.5 Compressive Test on Concrete

3.5.1 Concrete Mix Design

The concrete mixes for the present study comprised of Ordinary Portland cement concrete and nine fly ash and GGBS concrete mixes to investigate their enhancement effect on concrete strength. The details of the concrete mix design are given in Tables 3.4.

Mix proportion of M100 grade HPC mix was obtained by making certain modifications in the mix proportion arrived at using the guidelines of IS Code method. The mix proportion was obtained without considering any replacement of cement by SCMs.

After several trials, a cement content of 650 kg/m^3 and water-binder ratio of 0.24 were finalized based on 28 days compressive strength gain of HPC mix and desired workability properties (slump flow). Thus, for making HPC mixes the mix proportion was as follows:

Cement (Binder) content - 650 kg/m3

Water-binder ratio- 0.24,

Fine aggregate- 695 Kg/m^3

20 mm aggregate- 735 Kg/m^3

10 mm aggregate- 246 Kg/m^3

Water- 156 Kg/m^3

Chemical admixture- 0.9%

Aggregate/Binder ratio- 2.58

Table 3.4: Mix proportions of concrete mixes

Mix No.	Proportions %			Cement (kg)	FA (kg)	GGBS (kg)	Water (kg)	w/c ratio
	OPC	FA	GGBS					
N1	100	0	0	650	0	0	156	0.24
T1	60	16	24	390	104	156	130	0.2
T2	60	18	22	390	117	143	130	0.2
T3	60	20	20	390	130	130	130	0.2
T4	55	18	27	357.5	117	175.50	130	0.2
T5	55	20.25	24.75	357.5	131.63	160.87	130	0.2
T6	55	22.5	22.5	357.5	146.25	146.25	130	0.2
T7	50	20	30	325	130	195	130	0.2
T8	50	22.5	27.5	325	146.25	178.75	130	0.2
T9	50	25	25	325	162.5	162.5	130	0.2

3.5.2 Preparation of HPC

The required quantities of all the ingredients were taken by weigh batching. Mixing of the ingredients was done in a pan mixer as per the standard procedure. A reference mix was prepared using a water-binder ratio of 0.24 and suitable super plasticizer content was added in order to get desired workability.

The workability of the concrete was studied by conducting slump flow tests as per the standard procedure. Standard cube specimens of 150mm x 150mm x 150mm size were casted using the procedure described in IS Code (IS: 516–1959) and were immediately covered with plastic sheet and kept there for 24 hours and then released in water tank for curing.

All the HPC mixes were prepared using the same mix proportion and water-binder ratio and considered for study of workability and strength properties of HPC mixes.

For each of concrete mixes, 15 concrete cubes were cast for strength tests. All the concrete cubes were de-moulded within 24 hours of casting.

The cubes cast were stored in the same curing environments and for varying durations. The cubes were then removed from curing in accordance to their curing ages. They were then surface dried by air drying. The cubes were then placed carefully in the Concrete Testing Machine (CTM) and tested at a pace rate of 5 KN/sec.

The compressive strength of the cubes were determined using CTM of 3000 KN capacity in accordance with the procedures laid down in IS 516:1959.

3.5.3 Age of Testing

For each mix, sets of three cubes were cast and cured and these were then tested at each of the following test ages: 3 days, 7 days, 14 days and 28 days. A total of 120 cubes were cast and tested.

Fig 3.1: Cubes during curing

Chapter 4

Results and Discussions

4.1 General

The observations of the various tests that were conducted such as sieve analysis, dry loose bulk density (DLBD), water absorption test of sand and aggregates, determination of specific gravity of sand and aggregates and compressive test of concrete have been analyzed and the behavior is studied. The results of the analysis are discussed in the subsequent sections.

Fig 4.1: Compression Testing Machine (3000 KN Capacity)

4.2 Sieve Analyses

This is the mean given to the operation of dividing a sample of crushed sand into various fractions each consisting of particle of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of crushed sand, which we called gradation.

The result of sieve analyses for the sand used in the present experimental investigation is given in Table 4.1

Table 4.1: IS Sieve Analysis of Crushed Sand

Sieve	Average Weight (gm)	Percentage retained	Cumulative % retained	Cumulative % passing
4.75 mm	15.18	1.518	1.518	98.482
2.36 mm	219.1	21.91	23.428	76.572
1.18 mm	238.2	23.82	47.248	52.752
600 micron	137.2	13.72	60.968	39.032
300 micron	90.7	9.07	70.038	29.962
150 micron	84.6	8.46	78.498	21.502
pan	215.02	21.502	100	0

From the above results it has been observed that the crushed sand used in this experimental programme lies in the Zone II.

Fineness Modulus = sum of cumulative % retained/100

= 281.698/100

= 2.816

Since, the fineness of the sample lies between 2.6-2.9, the sand used is medium sand (IS: 2386 (Part I) - 1963)

4.3 Dry Loose Bulk Density (DLBD)

Dry loose bulk density is the ratio of weight of dry aggregate to the total aggregate volume. The result of the DLBD of the aggregate sample used in the present experimental investigation is given in Table 4.2.

Table 4.2: DLBD for Coarse aggregate

Sample	Percentage of CA-I (20 mm)	Percentage of CA-II (10 mm)	DLBD (kg/m^3)
1	100	0	1487
2	75	25	1585
3	50	50	1533
4	25	75	1543
5	0	100	1500

From the above observations, best combination is 75% of 20 mm aggregate and 25% of 10 mm aggregate and hence the same combination is applied throughout the whole experimental procedure.

4.4 Compressive Strength of concrete

The mean of compressive strength results for all the mixes are given in Table 4.3.

Table 4.3: Compressive Strength Results

Mix No.	Mix Proportions of Binders (%)			Strength @3days (MPa)	Strength @7days (MPa)	Strength @14days (MPa)	Strength @28days (MPa)
	OPC	FA	GGBS				
N1	100	0	0	69.36	81.27	88.20	99
T1	60	16	24	56.34	61.97	75.72	93.13
T2	60	18	22	58.70	67.90	80.90	96.70
T3	60	20	20	61.06	76.6	89.4	100
T4	55	18	27	52.03	65.06	78.33	91.25
T5	55	20.25	24.75	55.33	67.9	79.73	90.45
T6	55	22.5	22.5	58.63	76.53	87.53	96.23
T7	50	20	30	54.33	66.28	82.38	95.15
T8	50	22.5	27.5	54.53	69.16	82.46	94
T9	50	25	25	54.73	72.06	82.26	89.13

Fig 4.2: Cubes after Compression Testing

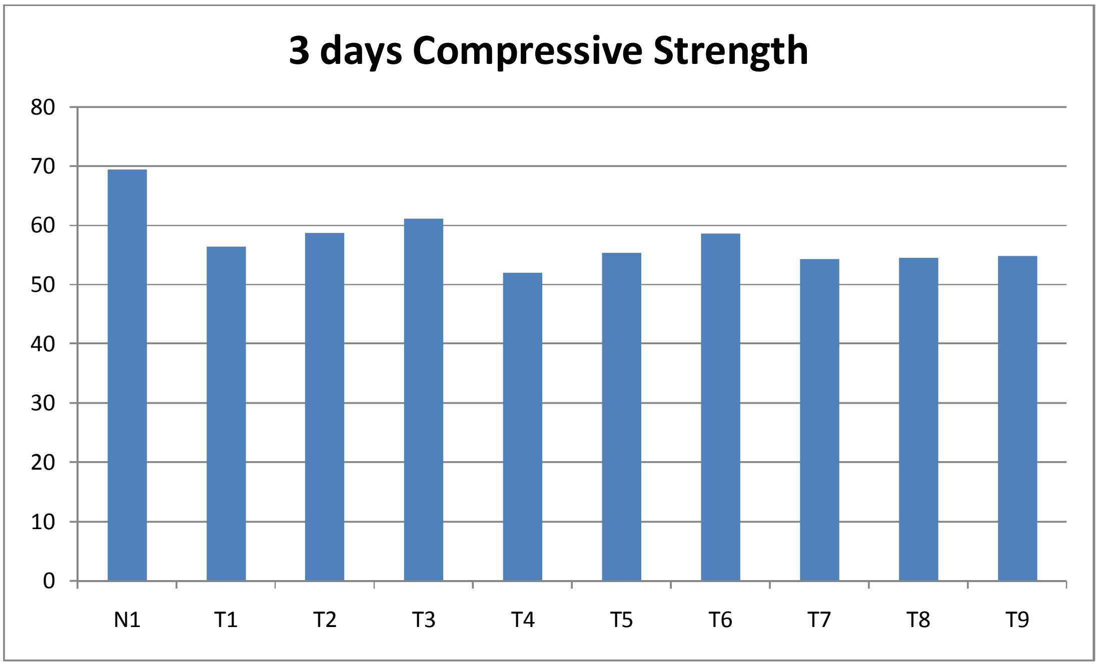

Fig 4.3: 3 Days compressive strength of concrete (MPa)

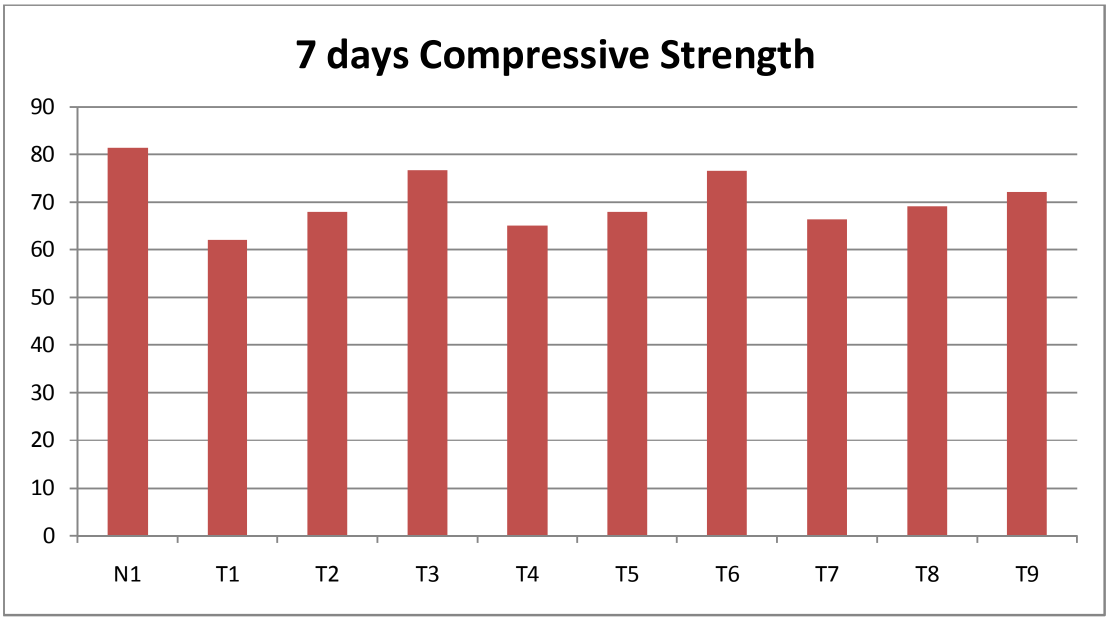

Fig 4.4: 7 Days compressive strength of concrete (MPa)

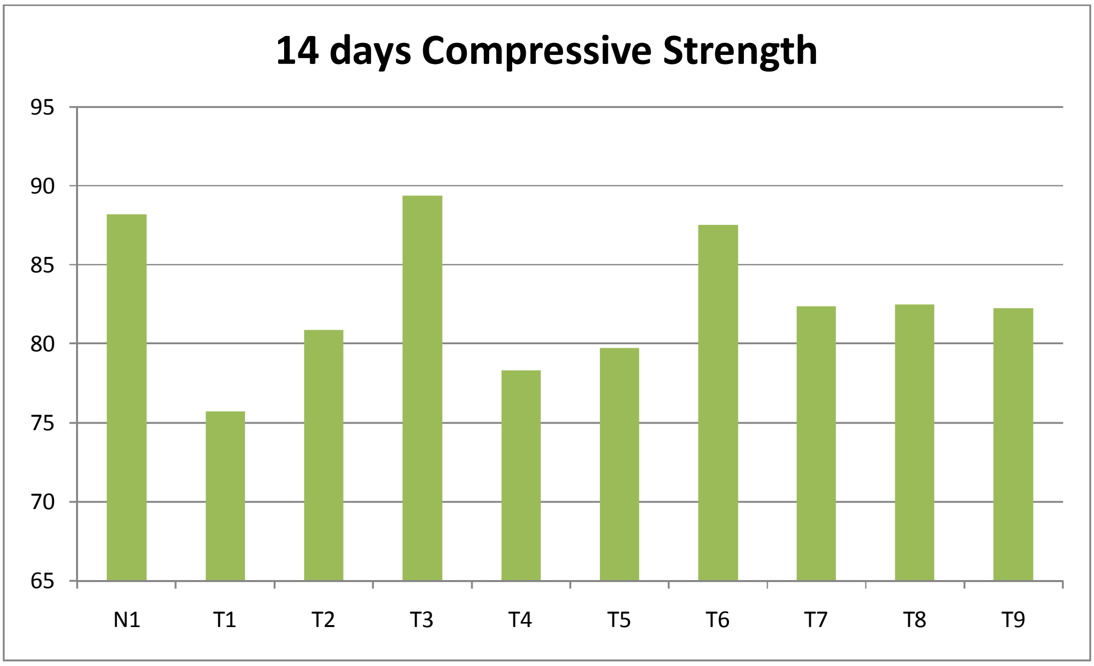

Fig 4.5: 14 Days compressive strength of concrete (MPa)

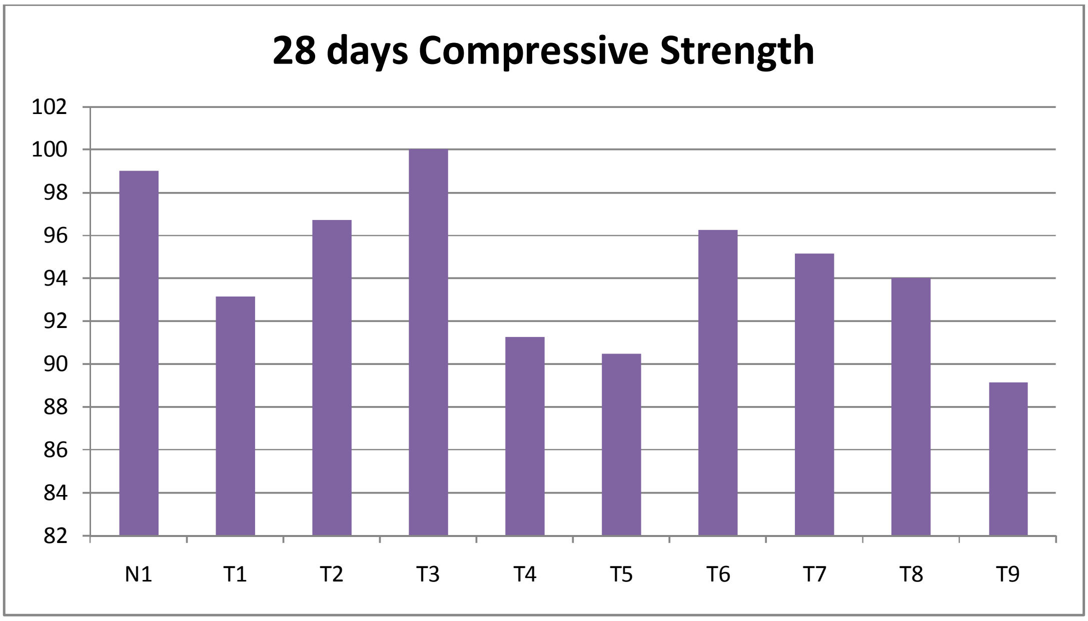

Fig 4.6: 28 Days compressive strength of concrete (MPa)

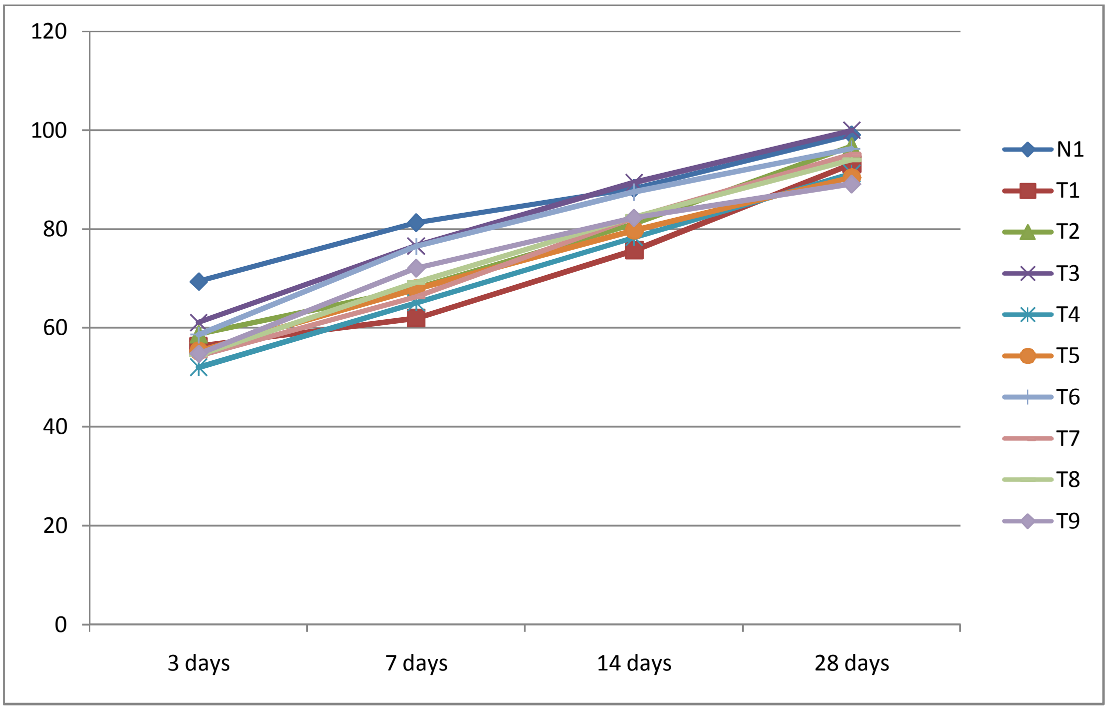

Fig 4.7: Comparison of increase of rate of strength of different concrete mixes

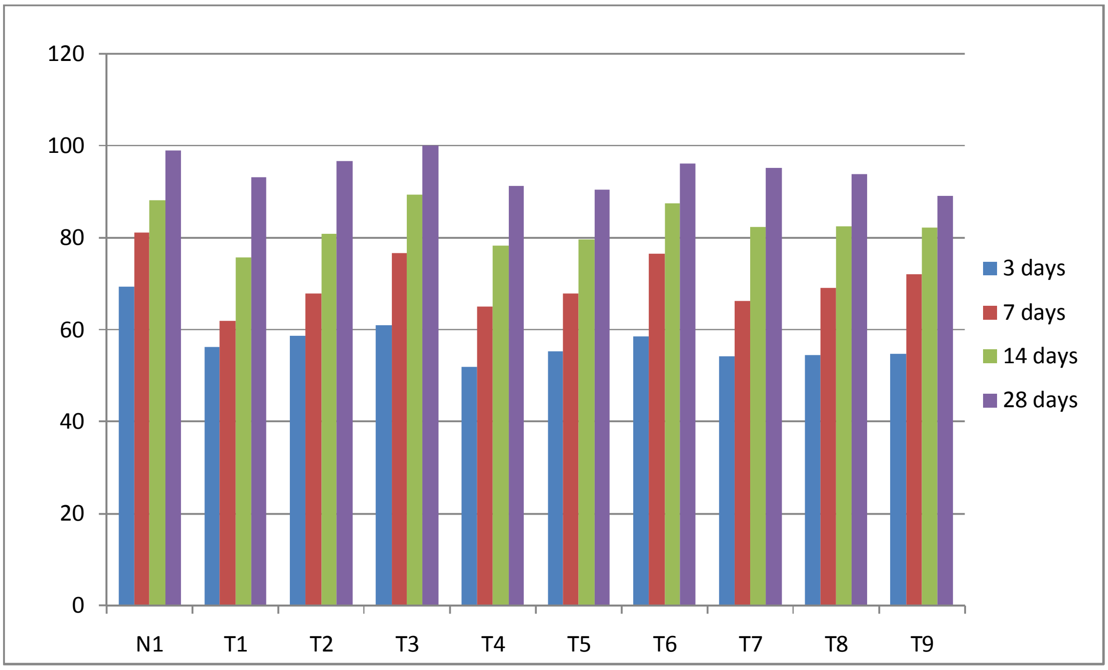

Fig 4.8: Compressive strength of concrete on 3 days, 7 days, 14 days and 28days

Chapter 5

Prediction of Strength Using Soft Computing Technique and Statistical Modeling

5.1 General

A number of improved prediction techniques have been proposed by various researchers including empirical or computational modeling, statistical techniques and artificial intelligence approach. A number of research efforts have concentrated on using multivariable regression models to improve the accuracy of predictions. Statistical models have the attraction that once fitted, they can be used to perform the predictions much more quickly than other modeling techniques and are correspondingly, simpler to implement in software. Apart from its speed, statistical modeling has the advantage over other techniques that are mathematically rigorous and can be used to define confidence intervals for the predictions. This is especially true when statistical modeling is compared with the artificial intelligence based techniques. Statistical analysis can also provide insight into the key factors influencing 28 days compressive strength through co-relation analysis.

Following sections give an overview of the theoretical aspects of the regression and correlation analysis.

5.2 Regression and Correlation Analysis

Regression and correlation analysis show that how to determine both the nature and the strength of a relationship between two variables. It will be possible to predict, with some accuracy, the value of an unknown variable based on past observation of that variable and other related ones.

The term regression was first used as a statistical concept in the year 1887 by Sir Francis Galton. He designed the word regression as the name of general process of predicting and variable from another. Later, statisticians coined the term multiple regression to describe the process by which several variable are used to predict another.

In regression analysis, an estimating equation is developed that is a mathematical formula that relates the known variable to unknown variable.

In regression analysis, only one dependent variable can be predicted or estimated. However, more than one independent variable can be used for analysis i.e. maximum only one output is predicted by using more than one input. Generally, the accuracy of prediction is increases by increasing the inputs. (Independent variable)

Frequently, a casual relationship between variables is developed; that is the independent variable "causes" the dependent variable to change. But in many cases, some other factor causes the change in both the dependent and the independent variables.

For this reason, it is important that one considers the relationships found by regression to be relationships association but not necessarily of cause and effect. Unless there are specific reasons for believing that the values of the dependent variables are caused by the values of the independent variable(s), the analysis could any be a partially complete one.

5.3 Multiple regression analysis

When more than independent variable is used to estimate the dependent variable and attempt is made to increase the accuracy of estimate then this process is called as multiple regression analysis. It is based on the same assumptions and procedures as in simple regression. The principle advantage of multiple regression analysis is that it allows to utilize more of variable information may be insufficient to determine a reliable estimating equation.

Multiple regression analysis is three – step process as follows:

1. Describe the multiple regression equation.
2. Examine the multiple regression standard error of estimate.
3. Use the multiple correlation analysis to determine how the regression equation.

In multiple regression more than one independent variable are used and they can be denoted as

X_1, X_2 etc.

Case 1

In symbolic form, the following formula is used for two independent variables:

$$\mathbf{Y = a + b_1X_1 + b_2X_2}$$

Where,

Y = estimated value corresponding to the dependent variable.

a = Y-intercept.

$\mathbf{X_1}$ and $\mathbf{X_2}$ = values of the two independent variables.

$\mathbf{b_1}$ and $\mathbf{b_2}$ = slopes associated with $\mathbf{X_1}$ and $\mathbf{X_2}$ respectively.

The main problem is to fit the best possible plane. To do this, the least squares criterion is used and located the plane that minimizes the sum of squares of the errors; that is the distances from the points around the plane to the corresponding points on the plane.

Case 2

In complex multiple regression involving ‘I’ number of independent variables the formula is given as:-

$$\mathbf{Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_iX_i}$$

Where,

$\mathbf{X_1, X_2, X_3, \ldots, X_i}$ = values of ‘i’ number of independent variables.

$\mathbf{b_1, b_2, b_3, \ldots, b_i}$ = slopes associated with $X_1, X_2, X_3, \ldots, X_i$.

The above formula for 'i' number of independent variables can be solved by the following equations:-

$$\sum Y = n\,a + b_1 \sum X_1 + b_2 \sum X_2 + b_3 \sum X_3 + \ldots + b_i \sum X_i$$

$$\sum X_1 Y = a \sum X_1 + b_1 \sum X_1^{2\,+}\ b_2 \sum X_1X_2 + b_3 \sum X_1X_3 + \ldots + b_i \sum X_i$$

$$\sum X_2 Y = a \sum X_2 + b1 \sum X_1X_2 + b_2 \sum X_2^2 + b_3 \sum X_2X_3 + \ldots + b_i \sum X_i$$

$$\sum X_i Y = a \sum X_i + b_1 \sum X_1X_i + b_2 \sum X_2X_i + b_3 \sum X_3X_i + \ldots + b_i \sum X_i^2$$

5.4 Methodology of Statistical Analysis

In the Present investigation, a multiple regression analysis technique was adopted to develop the equation and predict the various concrete mixes. The SPSS (Version 16) software was used for performing the regression analysis.

In the multiple regression analysis, various formulae are developed by varying the input parameters to predict the compressive strength corresponding to 3, 7, 14 and 28 days curing. Selection of equations with different inputs, which would help the users to predict the strength of such, mixes with available data/input parameters.

5.5 Formulae Derived from the Analysis

Based on laboratory result and using SPSS statistics program a linear regression model is developed which correlates the compressive strength of concrete with four independent variable as cement, fly ash, GGBS, w/c ratio and one dependent variable as Compressive strength.

The formulae derived from the multiple regression analysis in respect of various concrete mixes comprising different combination of ingredient and having been cured for different curing periods are as below

5.5.1Formulae for compressive strength

Compressive Strength at 3 days

$$= 5.0594 \times 10^{-4} \times C + 0.0057 \times FA - 0.12132 \times GGBS - 139.79 \times W/C + 102.901$$

Compressive Strength at 7 days

$$= -6.639 \times 10^{-3} \times C + 0.1973 \times FA - 0.1518 \times GGBS + 338.5465 \times W/C + 0.018836$$

Compressive Strength at 14 days

$$= -1.02 \times 10^{-6} \times C + 0.13749 \times FA - 0.10242 \times GGBS + 193.5311 \times W/C + 41.7525$$

Compressive Strength at 28 days

$$= 9.897 \times 10^{-6} \times C - 0.0319 \times FA - 0.08159 \times GGBS - 308.235 \times W/C + 172.9765$$

Table 5.1: Summary of actual and predicted compressive strength for 3 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength (MPa)	Predicted Strength (MPa)	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	69.36	69.3514	-0.0124
T1	60	16	24	56.34	56.8158	0.837443
T2	60	18	22	58.70	58.4499	-0.42789
T3	60	20	20	61.06	60.084	-1.62439
T4	55	18	27	52.03	54.5499	4.61944
T5	55	20.25	24.75	55.33	56.38889	1.877836
T6	55	22.5	22.5	58.63	58.22663	-0.69277
T7	50	20	30	54.33	52.284	-3.91324
T8	50	22.5	27.5	54.53	54.32663	-0.37436
T9	50	25	25	54.73	56.36925	2.908057

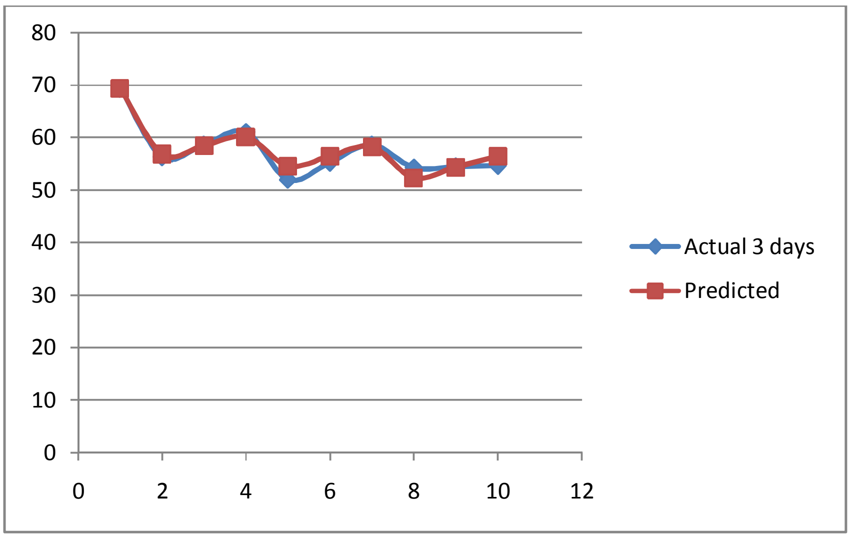

Fig 5.1: Variation of the actual and predicted compressive strength (3 Day's curing)

Table 5.2: Summary of actual and predicted compressive strength for 7 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	81.27	81.269996	-4.987E-06
T1	60	16	24	61.97	64.561128	4.0134490
T2	60	18	22	67.90	69.101027	1.7380740
T3	60	20	20	76.6	73.640926	-4.0182465
T4	55	18	27	65.06	64.165252	-1.39444321
T5	55	20.25	24.75	67.9	69.274384	1.9839721
T6	55	22.5	22.5	76.53	74.380024	-2.8905277
T7	50	20	30	66.28	63.769376	-3.9370371
T8	50	22.5	27.5	69.16	69.44424	0.4093207
T9	50	25	25	72.06	75.1191235	4.0723631

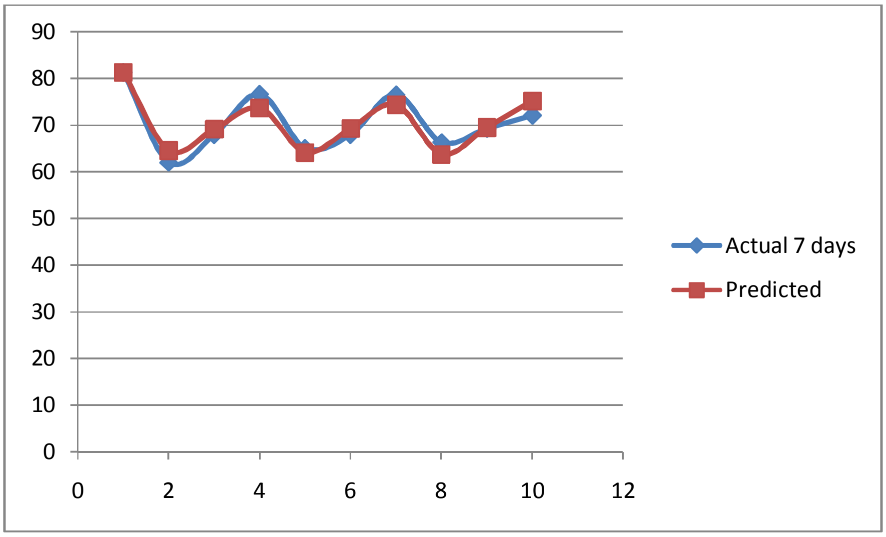

Fig 5.2: Variation of the actual and predicted compressive strength (7 Day's curing)

Table 5.3: Summary of actual and predicted compressive strength for 14 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	88.20	88.19999	-6.802E-06
T1	60	16	24	75.72	78.7804	3.8847215
T2	60	18	22	80.90	81.89925	1.2201046
T3	60	20	20	89.4	85.01811	-5.1546658
T4	55	18	27	78.33	78.5706	0.3062648
T5	55	20.25	24.75	79.73	82.08052	2.8636744
T6	55	22.5	22.5	87.53	85.58803	-2.2697382
T7	50	20	30	82.38	78.36081	-5.908174
T8	50	22.5	27.5	82.46	82.25938	-0.288708
T9	50	25	25	82.26	86.15795	4.524174

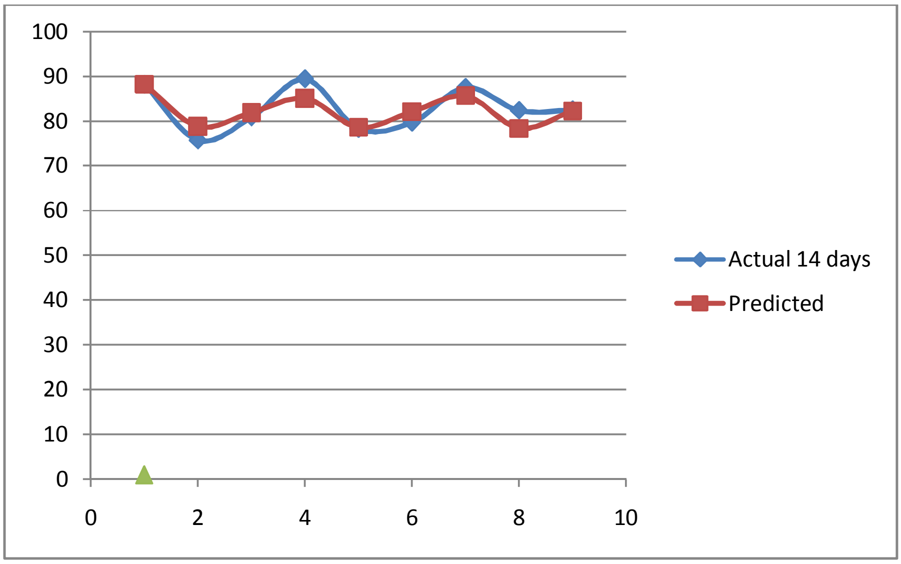

Fig 5.3: Variation of the actual and predicted compressive strength (14 Day's curing)

Table 5.4: Summary of actual and predicted compressive strength for 28 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	99	98.99367	-0.0064
T1	60	16	24	93.13	95.28	2.256507
T2	60	18	22	96.70	95.92597	-0.8069
T3	60	20	20	100	96.57194	-3.54975
T4	55	18	27	91.25	93.27462	2.170598
T5	55	20.25	24.75	90.45	94.00158	3.778215
T6	55	22.5	22.5	96.23	94.72805	-1.58554
T7	50	20	30	95.15	91.26923	-4.252
T8	50	22.5	27.5	94	92.0767	-2.08881
T9	50	25	25	89.13	92.88416	4.041764

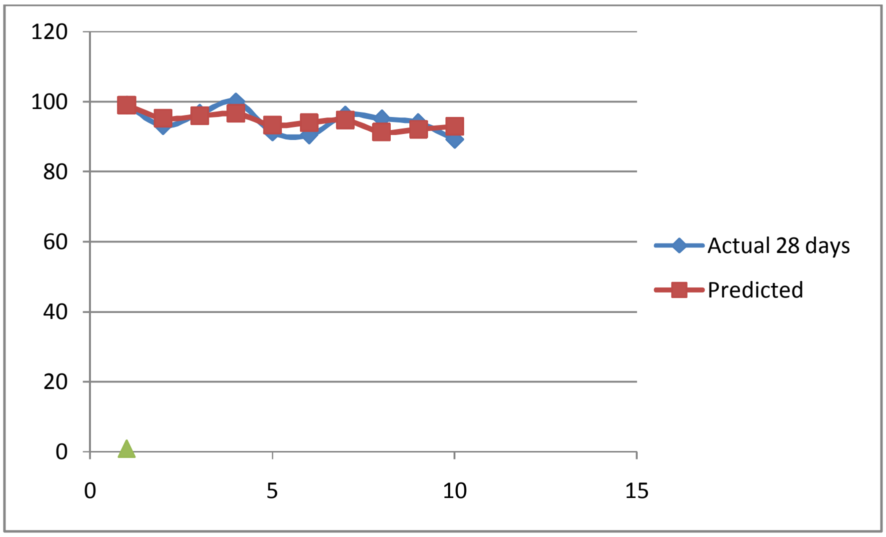

Fig 5.4: Variation of the actual and predicted compressive strength (28 Day's curing)

5.6 Artificial Neural Network (ANN)

Artificial neural networks are 'biologically' inspired networks. They have the ability to learn from empirical datal information. They find use in computer science and control engineering fields.

In recent years artificial neural networks (ANNs) have fascinated scientists and engineers all over the world. They have the ability to learn and recall - the main functions of the (human) brain. A major reason for this fascination is that ANNs are 'biologically' inspired. They have the apparent ability to imitate the brain's activity to make decisions and draw conclusions when presented with complex and noisy information. However there are vast differences between biological neural networks (BNNs) of the brain and ANN s.

A thorough understanding of biologically derived NNs requires knowledge from other sciences: biology, mathematics and artificial intelligence. However to understand the basics of ANNs, a knowledge of neurobiology is not necessary. Yet, it is a good idea to understand how ANNs have been derived from real biological neural systems. The soma of the cell body receives inputs from other neurons via adaptive synaptic connections to the dendrites and when a neuron is excited, the nerve impulses from the soma are transmitted along an axon to the synapses of other neurons. The artificial neurons are called neuron cells, processing elements or nodes. They attempt to simulate the structure and function of biological (real) neurons. Artificial neural models are loosely based on biology since a complete understanding of the behaviour of real neuronal systems is lacking. The point is that only a part of the behavior of real neurons is necessary for their information capacity. Also, it is easier to implement/simulate simplified models rather than complex ones.

Concrete is an essential material in civil engineering, which is widely used all over the world. It is a composite material comprising of key constituents, namely, cement, sand (as fine aggregate), fly ash, coarse aggregate, admixture and water. The properties of concrete, including its compressive strength are a highly nonlinear function of its constituents. Various studies have shown that concrete strength not only depend on water-to-cement ratio, but is also related to the other additive constituents. The lack of standard empirical relationships to judge the compressive strength of concrete based on its constituents has created the interest of the researchers towards soft computing tools. Soft Computing is defined as an emerging collection of methodologies which aim to exploit tolerance for imprecision, uncertainty and partial truth to achieve robustness, tractability and total low cost. Soft computing harnesses statistical, probabilistic and optimization tools for learning, predicting and classifying new patterns based on the past data. Artificial Neural Networks (ANNs) touted as the next generation of computing forms a sub-set of Soft Computing Tools. Artificial neural networks are massively parallel adaptive networks of simple nonlinear computing elements called neurons, which are intended to Abstract and model some of the functionality of human nervous system in an attempt to partially capture some of its computational strengths. As compared to conventional digital computing techniques, and procedural and symbolic processing, neural networks are advantageous because they can learn from example and generalize solutions to new renderings of a problem, can adapt to fine changes in the nature of a problem, are tolerant to errors in the input data, can process information rapidly, and are readily transportable between computing systems. The unconventional method of deriving information through learning has created immense interest in the field of neural networks. The capability of artificial neural networks to act as universal function approximator has been traditionally used to model problems in which the relationship between the dependent and independent variable is not clearly understood. Due to the black-box nature of neural networks, there is no need to assume any functional relationship among the various variables. ANNs automatically constructs the relationships and adapts itself based on the data used for training. ANNs modeling ability to derive meaning from unknown and non-linear interrelationships among variables have been harnessed to aid the prediction of behavior of engineering and natural systems. Concretes compressive strength is one such problem that is unstructured in nature involving highly non-linear relationships among its constituents and compressive strength.

The unconventional method of deriving information through learning has created immense interest in the field of neural networks. The capability of artificial neural networks to act as universal function approximator has been traditionally used to model problems in which the relationship between the dependent and independent variable is not clearly understood. Due to the black-box nature of neural networks, there is no need to assume any functional relationship among the various variables. ANNs automatically constructs the relationships and adapts itself based on the data used for training. ANNs modeling ability to derive meaning from unknown and non-linear interrelationships among variables have been harnessed to aid the prediction of behavior of engineering and natural systems.

Table 5.5: Summary of actual and predicted compressive strength for 3 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	69.36	64.22845	-7.98953
T1	60	16	24	56.34	59.0117	4.527441
T2	60	18	22	58.70	59.097	0.6718
T3	60	20	20	61.06	59.1875	-3.16369
T4	55	18	27	52.03	58.6044	11.21829
T5	55	20.25	24.75	55.33	58.6882	5.722176
T6	55	22.5	22.5	58.63	58.7786	0.252765
T7	50	20	30	54.33	58.2991	6.808182
T8	50	22.5	27.5	54.53	58.3804	6.595301
T9	50	25	25	54.73	58.4693	6.395333

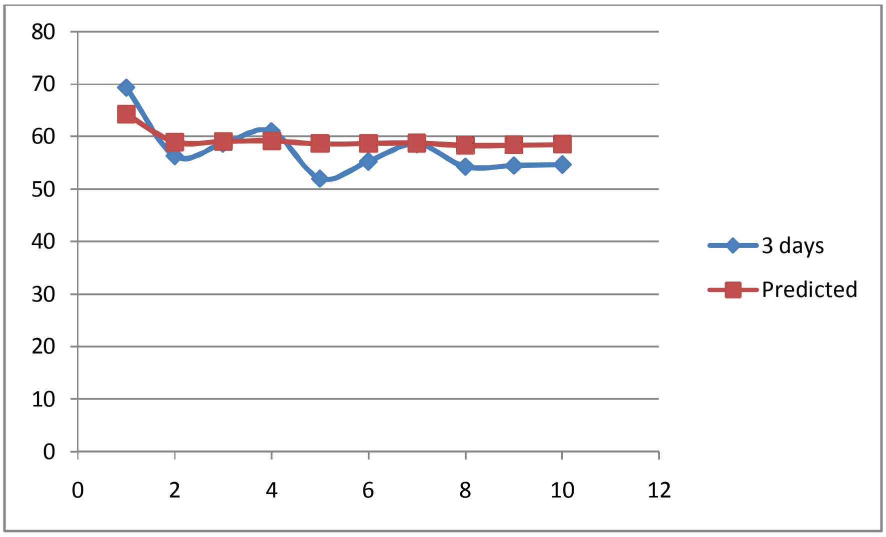

Fig 5.5: Variation of the actual and predicted compressive strength (3 Day's curing)

Table 5.6: Summary of actual and predicted compressive strength for 7 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	81.27	81.26692	-0.00379
T1	60	16	24	61.97	63.10378	1.796693
T2	60	18	22	67.90	67.39889	-0.7435
T3	60	20	20	76.6	76.77455	0.227358
T4	55	18	27	65.06	64.40381	-1.01887
T5	55	20.25	24.75	67.9	68.23651	0.493158
T6	55	22.5	22.5	76.53	76.44471	-0.11157
T7	50	20	30	66.28	65.25055	-1.57769
T8	50	22.5	27.5	69.16	68.04114	-1.64439
T9	50	25	25	72.06	75.27232	4.267597

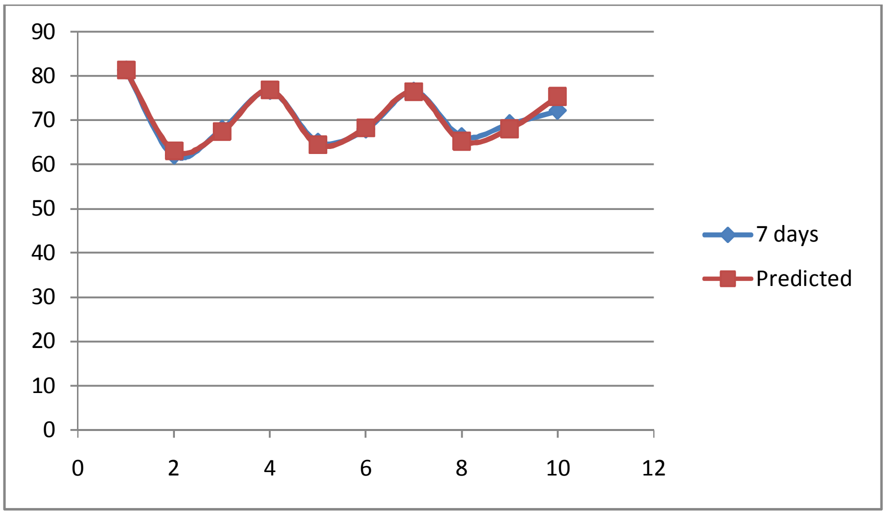

Fig 5.6: Variation of the actual and predicted compressive strength (7 Day's curing)

Table 5.7: Summary of actual and predicted compressive strength for 14 Day's curing

Mix No.	Mix Proportions of Binders (%)			Actual Strength	Predicted Strength	Percentage Difference
	OPC	FA	GGBS			
N1	100	0	0	88.20	88.24895	0.055465
T1	60	16	24	75.72	76.83602	1.452465
T2	60	18	22	80.90	81.28535	0.474067
T3	60	20	20	89.4	87.86726	-1.74438
T4	55	18	27	78.33	76.3476	-2.59655
T5	55	20.25	24.75	79.73	80.11629	0.482167
T6	55	22.5	22.5	87.53	87.70743	0.202298
T7	50	20	30	82.38	76.02917	-8.35314
T8	50	22.5	27.5	82.46	79.10229	-4.24477
T9	50	25	25	82.26	87.51197	6.001426

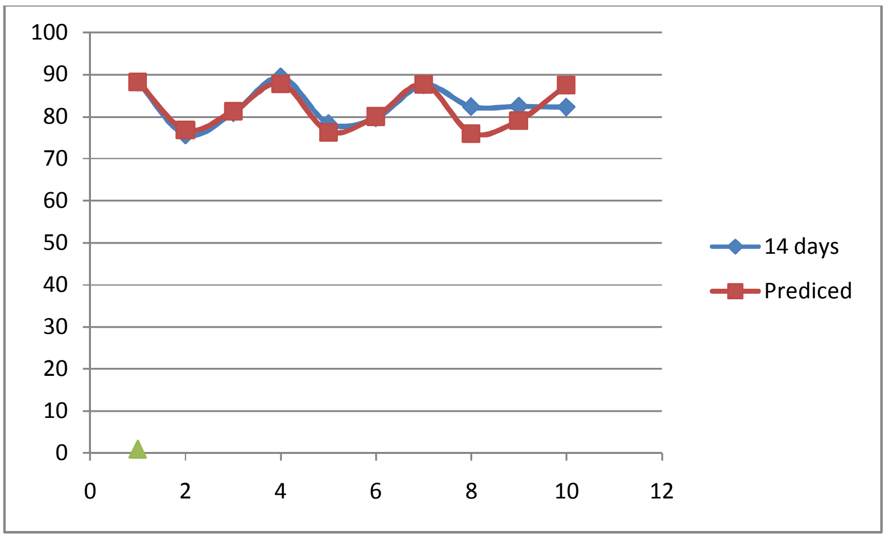

Fig 5.7: Variation of the actual and predicted compressive strength (14 Day's curing)

5.7 Concluding Remarks

The theoretical aspects of regression analysis and ANN are covered in this chapter. Further, the models based on regression approach and ANN are developed. The models so developed are capable of predicting the compressive strength of concrete. It is found that the difference in predicted values and actual values of compressive strength of concrete is less.

The range of Coefficient of correlation and ANN in respect of the prediction of compressive strength when compared with actual values of compressive strength, it is seen that there is better agreement in the predicted values and actual values of compressive strength.

Chapter 6

Summary and Conclusion

6.1 General

The objective of this investigation was to assess the compressive strength of concrete in ternary mixes with replacement of cement more than 40% with SCMs. The SCMs used in this project were industrial waste present in abundance. In this investigation a new ultra-fine SCM P100 was used in project. In a view to evaluate the effect of SCMs on the behavior of compressive strength of concrete. A systematically planned experimental investigation was conducted.

As a part of experimental study, the cement was replaced by ultra-fine fly ash & GGBS. In this study the percentage of cement replaced with SCMs was 40%, 45%, and 50%. Each replacement was further divided into three parts with varying composition of fly ash and GGBS. Three periods of curing (3days, 7days, 14 days and 28 days) for testing of compressive strength was considered.

Further, the result obtained in the experimental investigation was used, to predict compressive strength of concrete using Soft computing technique and multi linear regression. The values of the predicted strength of concrete were further compared with actual values of strength.

6.2 Conclusion

Some of the broad conclusions deduced from the present study are as follows.

i. It has been observed that Mix T3 (60% cement-20% fly ash -20% GGBS) was giving maximum strength of 89.4 MPa at 14 days & 100 MPa at 28 days curing.
ii. As there is substantial saving of quantity of cement in 50% replacement of it, and the strength given by mix T8 (50% cement-22.5% fly ash -27.5% GGBS) was 94 MPa.
iii. It was observed that in (40%, 45%) type of replacement the maximum strength was given by Mix having (50% F.A-50% GGBS).
iv. The strength of T3 was more than N1 (100% cement) at 14 days and 28 days curing.
v. Mix N1 (100% cement) gave maximum strength of 69.36 MPa at 3 days & 81.27 MPa at 7 days.
vi. In MLR and ANN the predicted compressive strength of concrete gives better agreement than actual compressive strength of concrete.

6.3 Summary

From the detailed discussion of the results as mentioned in Chapter 4 and Chapter 5 and the conclusion pointed out in the afore-mentioned section indicates that the waste material such as fly ash (P100) and GGBS can be used effectively in the civil engineering construction for high strength concrete mixes. And there is substantial saving in quantity of cement, so less production of cement is required so environmental degradation is reduced, thus it also helps in sustainable development.

Chapter 7

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