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SYNERGISTIC EFFECTS IN TERNARY BLENDED CEMENTITIOUS SYSTEM CONTAINING FLY ASH AND SILICA FUME

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ABSTRACT

This paper presents a detailed experimental investigation on the synergestic effects on ternary blended cementitious system containing fly ash and silica fume. The experimental programme consisted of three parts, the first part was to obtain the super plasticizer demand for each mix so as to obtain a workability of 110±5%, the second part was to determine the strength and durability properties of the mortar samples having different fly ash and silica fume contents and the third part was to determine the synergy existing in the ternary blends both in terms of durability and strength. Test results have shown that the ternary blended mixtures improved the mortar performance by improving the workability, strength and durability, therefore are applicable. Ternary mixtures performed in accordance with their ingredients; however the degree of improvement that they contribute varies based on the selected dosage and type of SCMs. Synergy between the fly ash and silica fume is the main reason for the outstanding performance of ternary mixtures. The results obtained thus are encouraging for partial replacement.

Keywords: Synergic action; Ternary blended concrete; Durability; Fly ash; Silica fume; Concrete

1. INTRODUCTION

Cement is the most widely used construction material in the world. Due to the huge quantity of consumption, its performance and environmental footprint on the earth are of great importance. Sustainability and durability have become the major concern of the construction industry.

1.1 Environmental Impacts of cement production

Energy consumption is the biggest environmental concern with cement production. Cement production is the most energy intensive of all the industrial manufacturing processes. Including direct fuel use for mining and transportation of raw materials, cement production takes about 1758KWh for every ton of cement.

The industry's heavy reliance on coal leads to especially high emission levels of carbon dioxide, nitrous oxide and sulphur among other pollutants. Thus Portland cement is not only one of the most energy intensive materials of construction but also is responsible for a large amount of greenhouse gas emissions. The world's yearly cement production of 1.6 billion tones accounts for about 7-8% of global loading of carbon dioxide into the atmosphere.

There are two different sources of carbon dioxide emissions during cement production, namely the combustion of fossil fuels to operate the rotary kiln and the chemical process of calcining limestone into lime. Combining these two sources, for every ton of cement production approximately one ton of carbon dioxide is released into the atmosphere. Furthermore, mining large quantity of raw materials, such as limestone and clay, and fuel such as coal, often results in extensive deforestation and top soil loss.

The environmental impact of the construction industry can be reduced through resource productivity i.e. by conserving materials and energy in the cement production and by improving durability of concrete products. Cement conservation is the first step in reducing the energy consumption and greenhouse gas emissions.

One of the efforts to mitigate the environmental issues associated with cement production includes partial replacement of cement with supplementary cementitious materials like fly ash, silica fume, rice husk ash etc. Using supplementary cementitious materials (SCMs) is an effective way of reducing carbon footprint of our cement production.

1.2 Durability and quality of structures

Construction industry is becoming increasingly complex and the importance of building structures that are both cost effective and durable has never been higher.Achieving durability in construction should be a very important consideration in the design and construction of new structures. Concrete structures are generally designed for service life of 50 years, but experience shows that in urban and coastal environment many structures begin to deteriorate in 20 to 30 years or even lesser time.

Durability of a structure is its resistance to weathering action, chemical attack, abrasion and other degradation process. Mineral additions have been an important tool to aid durability of concrete structure and thus came the concept of blends.

In recent years, many researchers have established that waste materials like fly ash, blast furnace slag, silica fume, metakaolin, rice husk ash etc. may be used as a partial replacement of cement, which lead to economy and in addition by utilizing the industrial wastes in a useful manner the environmental pollution is also reduced to a great extent and which in turn leads to sustainable development. Blends offer significant advantages over conventional system of Portland cement alone. They can produce stronger and more durable concrete and possess a long and impressive track record. Blends are also suitable for harsh environment where concrete is likely to be exposed to moisture, extreme weather and chemicals. Moreover blends are more environment friendly.

1.3 FLY ASH

Fly ash (FA) is the most widely used supplementary cementitious material in concrete; ASTM C 618-89 defines fly ash as “a finely divided residue that results from combustion of ground or powdered coal”.

It is a byproduct of the combustion of pulverized coal in electric power generating plants. Upon ignition in the furnace, most of the volatile matter and carbon in the coal are burned off. During combustion, the coal’s mineral impurities (such as clay, feldspar, quartz, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called fly ash. The fly ash is then collected from the exhaust gases by electrostatic precipitators or bag filters.

Two classes of fly ash are defined by ASTM C 618-89, Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite). Theburning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime. Class C Fly ash is produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, it also has some self-cementing properties. Class C fly ash generally contains more than 20% lime (CaO).

2. LITERATURE REVIEW

(1) "Use of ternary cementitious systems containing silica fume and fly ash in concrete", M.D.A Thomas (1999) conducted laboratory studies on durability of concrete that contains ternary blend of Portland cement, silica fume and a wide range of fly ashes.

(2) "Porosity and strength of PFA/SF/OPC ternary blended paste", Khan *et al*. (2000) conducted studies on a ternary blended cementitious system of ordinary Portland cement (OPC)/ pulverised fuel ash (PFA)/ silica fume (SF) for the development of high- performance concrete. Cement pastes covering a wide range of PFA/SF blending proportions were investigated.

(3) "Effects of densified silica fume on the microstructure and compressive strength of blended cement pastes", Rao (2003) reported the influence of silica fume (SF) on various preliminaryproperties of cement pastes and mortars. Specific gravity, air content and workability decrease as the addition of SF increases.

(4) "Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar", Chindaprasirt*et al.* (2008) studied the strength, porosity and corrosion resistance of mortars made with ternary blends of ordinary Portlandcement (OPC), ground rice husk ash (RHA) and classified fly ash (fine fly ash, FA). The results show that the use of ternary blend of OPC, RHA and FA significantly improves the mortar in terms of strength at the low replacement level and at the later age

(5) "Evaluation of binary and ternary blends of pozzolanic materials using rapid chloride penetration test", Ahmed *et al.* (2009)studied the effect of replacing cement by pozzolanic materials.The materials used were fly ash, blast furnace slag (BFS), and silica fume. The blending was at the increasing levels of 25, 50, and 70% of fly ash or BFS, with or without addition of silica fume at

10% cement replacement to form binary and ternary blends

(6) "Utilisation of fly ash with silica fume and properties of Portland cement- fly ash- silica fume concrete", Nochaiya*et al*. (2009) investigated ternary blends of fly ash, silica fume andPortland cement using an extensive range of mixes: fly ash from 5% to 30%, and silica fume at 2.5%, 5% and 10%.Fresh properties,in terms of the setting time of cement paste and the workability of the ternary blend concrete, were investigated. Compressive strength of the ternary concrete was tested and analyzed relative to both a Portland cement (PC) control and reference fly ash mixes.

(7) **"Effect of water to binder ratio, air content and type of cementitious materials on fresh and hardened properties of binary and ternary blended concrete"** by **Yurdakul*et al*. (2013)** investigated the effect of water-to-binder ratio (w/b), air content, and type of cementitious materials on fresh and hardened properties of binary and ternary blended concrete mixtures in pavements.

EXPERIMENTAL PROGRAMME

3.1 GENERAL

The experimental programme consisted of three parts, the first part was to obtain the superplasticizer demand for each mix so as to obtain a workability of 110±5%, the second part was to determine the strength and durability properties of the mortar samples having different fly ash and silica fume contents and the third part was to determine the synergy existing in the ternary blends both in terms of durability and strength.

3.2 MATERIALS

The materials used for the experimental work are ordinary Portland cement 53 grade, class F fly ash, silica fume, M sand, super plasticizer and water.

3.2.1 Ordinary Portland Cement (OPC)

OPC 53 grade, conforming to IS 12269, was used for the experimental work. Laboratory tests were conducted to determine the specific gravity, standard consistency, fineness, initial setting time, final setting time and the compressive strength. All tests were done as specified by IS 4031 (Part 1 to Part 5).The results are as shown in the Table 3.1.The chemical composition of cement was tested at Indian Institute of Technology (IIT) Madras and the results are presented in Table 3.2.

Table 3.1 Properties of Cement

SL NO:	PARTICULARS	VALUES
1	Grade	OPC 53
2	Specific Gravity	3.15
3	Standard Consistency	31.25%
4	Fineness	4%
5	Initial Setting Time	90 minutes
6	Final Setting Time	270 minutes
7	3rd day Compressive strength	28 N/mm^2
8	7th day Compressive strength	32 N/mm^2

Table 3.2 Chemical composition of cement

Oxide	Content (%)
CaO	63.48
SiO_2	19.13
Al_2O_3	4.26

Fe_2O_3	5.17
SO_3	4.10
MgO	0.67
$P2O_5$	0.62
TiO_2	0.22
Na_2O	0.60
K_2O	1.75

3.2.2 Fly ash

Class F fly ash was used for the experimental work and it was collected from Neptune Ready Mix Concrete plant, Trivananthapuram. The specific gravity the fly ash was found to be 2.08. Fineness of flyash were found out by wet sieve analysis using 45µm sieve.Result is shown in Table 3.3. The chemical composition of fly ash was tested at Indian Institute of Technology (IIT) Madras, and is presented in Table 3.4.Fig 3.2 shows the scanning electron microscope (SEM) images of FA obtained from IIT Madras.

Fig 3.1 Fly ash

Table 3.4 Chemical composition of fly ash

Chemical	% by mass
Component	
SiO_2	60.28
Al_2O_3	31.76
Na_2O	2.10
P_2O_5	1.42
SO_3	0.97
Fe_2O_3	0.89
CaO	0.72
K_2O	0.69
TiO_2	0.64
MgO	0.52

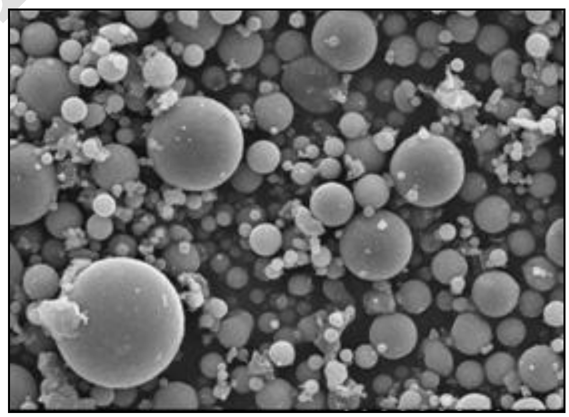

Fig 3.2 SEM images of fly ash

3.2.3 Silica fume

Silica fume used for the experimental work was obtained from ELKEM Materials. From the laboratory tests, thespecific gravity was obtained as 2.2 and density as 0.784 g/cc. Chemical

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composition of Silica Fume obtained from Indian Institute of Technology (IIT) Madrasis shown in Table 3.5.Fig 3.4 shows the scanning electron microscopic image of SF as obtained from IIT Madras.

Figure 3.3 Silica fume

Table 3.5 Chemical composition of silica fume

Oxide	Content (%)
CaO	2.94
SiO_2	84.28
Al_2O_3	1.54
Fe_2O_3	3.47
SO_3	2.34
MgO	2.09
$P2O_5$	0.60
TiO_2	0.04
Na_2O	1.23
K_2O	1.47

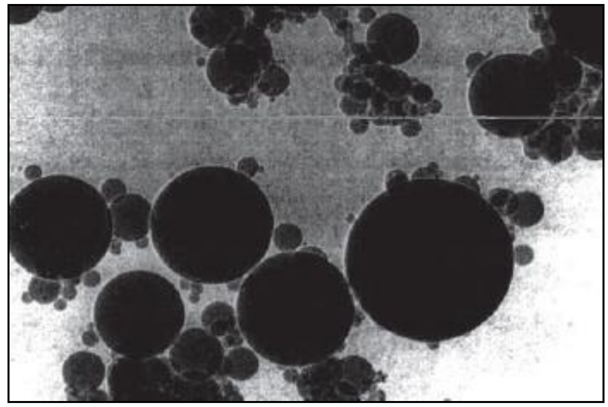

Fig 3.4 SEM image of silica fume

3.2.4 Fine Aggregates

Locally available M Sand was used as fine aggregate. Laboratory tests were conducted, as per IS: 383-1970, to determine the different physical properties of M sand. The details of particle size distribution are given in Table 3.6 and the grading curve is as represented by Fig. 3.3. The properties of fine aggregates are as shown in Table 3.7.

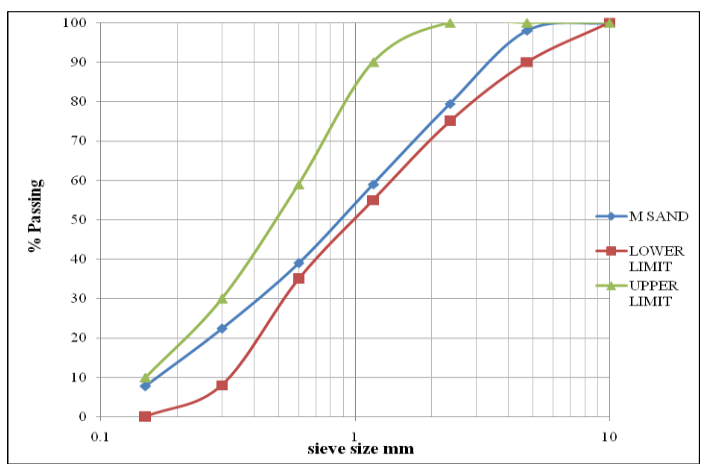

Fig.3.3. Gradation curve of fine aggregate

Table 3.7 Properties of fine aggregate.

Sl. No.	Particulars	Values
1	Specific gravity	2.50
2	Fineness Modulus	3.062
3	Grade	Zone II

3.2.5 Water

Clean and potable water available in the college water supply system was used for the work.

3.2.6 Superplasticiser

Conplast SP430 supplied by M/s Fosroc Chemical (India) Pvt. Ltd was used as superplasticiser.Conplast SP430 is based on SulphonatedNapthalenePolymers and supplied as a brown liquid instantly dispersiblein water.Conplast SP430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. The properties of Conplast SP430 as specified by the suppliers are as shown in Table 3.8.

Table 3.8 Properties of Conplast SP430

Specific Gravity	Typically 1.20 at 20°C
Chloride content	Nil
Recommended dosage	0.7 to 2.0 L/100kg of cement

3.3 MIX PROPORTION AND METHODOLOGY

3.3.1 Mix proportion

Mortar samples were prepared in the ratio 1:3 by weight, i.e. one part of cementitious materials to three parts of fine aggregate.

3.3.2 Methodology

3.3.2.1 Determination of superplasticiser demand

Superplasticiser demand for each mix was determined using flow table test to obtain a workability of 110±5%.

3.3.2.1 Mixing

Cementitious materials, fine aggregates, water and super plasticizer were taken in required proportions and each mortar sample was prepared using a standard mortar mixer. Ordinary Portland cement, fly ash, silica fume and fine aggregates were first dry mixed in the mixer for about three minutes and then water and superplasticizer is added and further mixed for three minutes to get a homogeneous mix.

Fig 3.6 Mortar mixer

3.3.2.2 Casting of specimens

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Mortar was cast into cubes, beams and discs. Standard moulds namely, 50mm X 50mm X 50 mm cube moulds, 40mmX 40mmX160mm beam moulds and disc moulds of 150mm diameter and 50mm thickness were used for casting. The mortar mix were filled in the moulds and vibrated using a vibrating table. The surface of the mortar were then finished using a trowel.

3.3.2.3 Curing Regime

All specimens were kept undisturbed for 24 hours and then weighed to obtain their dry weights and subsequently were subjected to water curing until the test ages were reached. The samples for durability studies were transferred to respective acid and sulphate solution after three days of water curing.

Fig 3.7 Curing of mortar specimens

Details of the specimens used for testing are given in Table 3.9

3.4 WORKABILITY OF MORTAR

Workability of mortar is its ease of use measured by the flow of the mortar. Superplasticiser demand for each of the nine mixes, to get a workability of 110±5% were determined by the flow test.

The standard flow tests uses a standard conical frustum shape of mortar with a diameter of four inches. This mortar sample is placed on a flow table and dropped 25 times within 15 seconds. As the mortar is dropped, it spreads out on the flow table. The initial and final diameters of the mortar sample are used to calculate flow. Flow or workability is defined as the increase in diameter divided by the original diameter multiplied by 100.

Figure 3.8 Flow Test

3.5 TESTS CONDUCTED

3.5.1 Compressive strength test

Compressive strength test measures the resistance of samples to gradually applied crushing load. Compressive strength of hardened mortar is the most important of all the properties. Therefore mortar is always tested for its strength before it is used in important works. The test was conducted as per IS 2250-1981, on 50mm x50 mmx 50mm cubical samples in a compression testing machine

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of capacity 2000KN at a loading rate of 6 N/mm^2.

The test was done for all the nine mixes for determining the 7th day, 28thday, 56th day as well as the 90th day compressive strength. For each test age of these mixes, three specimens were tested. Fig 3.8 shows the details of the test. The maximum load indicated by the testing machine was noted and compressive strength was calculated as;

$$f = \frac{P}{A}$$

Where;

f = Compressive strength (N/mm^2)

P = Maximum Load at failure (N)

A = Cross sectional area (mm^2)

Figure 3.9 Compression Testing Machine

The modulus of rupture is then calculated and reported as the flexural strength. The third-point loading test is preferred because, ideally, in the middle third of the span the sample is subjected to pure moment with zero shear. In the center-point test, the area of eventual failure contains not only moment induced stresses but also shear stress and unknown areas of stress concentration. Place the beam in the testing machine as shown in Figure 3.10 with its longitudinal axis normal to the supports. Apply the load vertically at the rate of 50 ±10 N/s until fracture. Three beam specimens for each test age where tested as per ASTM C 78 to determine the flexural strength of all the nine mixes.

Flexural strength was calculated as;

$$\sigma_f = {}^{M}/_{Z}$$

Where;

σ_f =Flexural strength (MPa)

M= Maximum bending moment (Nmm)

Z= Section modulus (mm^3)

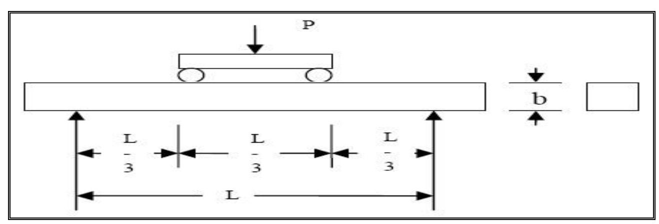

Figure 3.10 Third Point loading method

Fig 3.11 Flexural strength test on mortar beam

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3.5.3 Sulphate attack Test

Sulphate attack is one of the most severe environmental deteriorations that affect the long-term durability of concrete. The term sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. Because of the increase in volume of the solid phase, a gradual disintegration of concrete takes place.

Fig 3.12 Mortar specimens subjected to sulphate attack

3.5.4 Sulphuric Acid Attack Test

When concrete or mortar samples are exposed to acid solutions (pH less than 6.5) it will result in slow or rapid disintegration of the samples depending on the type and concentration of the acid.

Fig 3.13 Mortar specimens subjected to acid attack

3.5.5 Rapid Chloride Permeability Test (RCPT)

Rapid chloride permeability test measures the electrical conductance of mortar samples, which is a measure of resistance of mortar samples to chloride ion penetration.Itwas performed on 100mm diameter and 50mm thick mortar disc specimens, as per ASTM C 1202-94. In RCPT, the disc specimen is fitted between two cells having a hole of 10cm diameter at its center covered by a pocket or reservoir for filling the solution. One of the faces of the specimen is exposed to 3% NaCl solution and the other face is exposed to 0.3 M NaOH solution. Electrode dipped in NaCl will be connected to the negative terminal of the power supply and that of NaOH to the positive terminal. Electrical connections to voltage application and data read out apparatus; i.e. a millimeter is made. 60V dc is applied across the faces continuously for a period of 6 hours and the current between the electrodes is monitored at 30 minutes interval.

The total charge passed is a measure of the electrical conductance of the concrete during the period of the test and is calculated by the formula

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + \ldots.. + 2I_{300} + 2I_{330} + I_{360})$$

Where

Q = charge passed (coulombs)

Io =current (amperes) immediately after voltage is applied,

I_t= current (amperes) at t min after voltage is applied.

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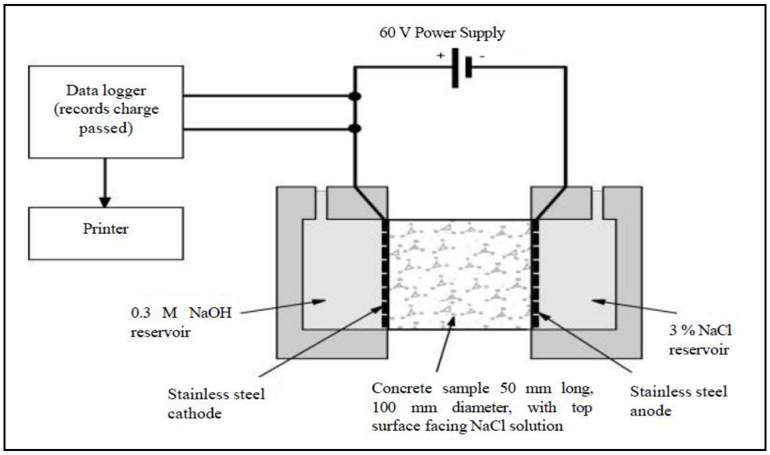

Figure 3.14 RCPT set up

Fig 3.15 RCPT specimen

Fig 3.16 RCPT setup in the laboratory

3.5.6 Sorptivity Test

Water is generally involved in every form of deterioration, and in porous solid, permeability of the material to water usually determines the rate of deterioration. The permeability of a mortar or concrete surface depends on many factors like mixture proportions, presence of chemical admixtures and supplementary cementitious materials, composition and physical characteristics of the cementitious component and of the aggregates, the entrained air content, type and duration of curing, presence of micro cracks, etc.

$$I = \frac{m_t}{a \times d}$$

Where,

I = normalized absorbed water (mm)

m_t= change in specimen mass at time t (g)

a= area of specimen exposed to water (mm^2)

d= density of water (g/ mm^3)

The initial rate of water absorption or sorptivity (mm/s$^{1/2}$) is defined as the slope of the line that is the best fit to Iplotted against the square root of time (s$^{1/2}$). Obtain this slope by using least squares, linear regression analysis of the plot of I versus time$^{1/2}$.

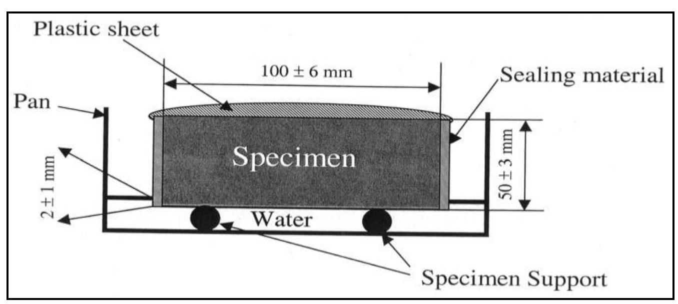

Fig 3.17 ASTM C 1585-04 standard test setup

RESULTS AND DISCUSSION

4.1 GENERAL

The strength and durability studies were conducted on all the nine mixes according to the procedures described in the previous chapter. The results obtained were tabulated and a detailed analysis and discussion on the results is presented in this chapter.Each test result plotted in the figures or in the tables is the mean value of results obtained by testing three specimens.The interpretation of the results obtained is based on the current knowledge available in the literature as well as on the nature of results obtained.

4.1 SUPERPLASTICISER DEMAND

Flow table test was conducted for all the nine mixes, to determine the superplasticizer dosage required to obtain a workability of 110±5%. Figure 4.1shows the quantity of superplasticiser required for 1kg of cementitious materials.

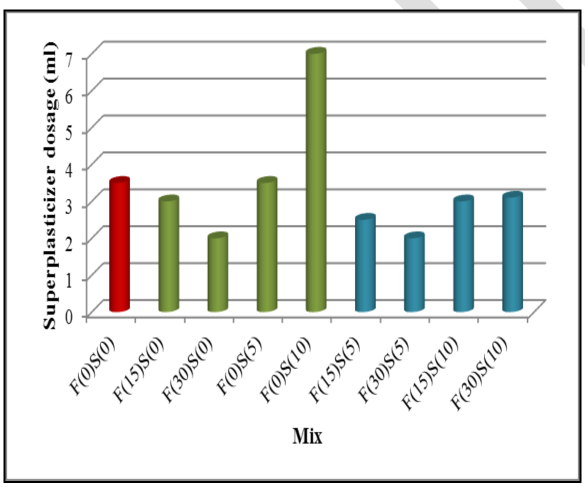

Figure 4.1 Superplasticiser demand for various mixes

4.2 UNIT WEIGHT

After demoulding the specimens, the unit weights of all the nine mixes were measured and the results are as presented in **Table 4.1.**It can be seen that maximum unit weight is obtained for control mix. As expected, the unit weight of the mortars with binary and ternary blends decreased with an increase in FA and SF content due to their low unit weight compared to that of cement. The unit weight of mortars with binary blends of FA/SF varied between 2.29 and 2.42 kg/m^3 whilst the unit weight of ternary blends of FA and SF ranged between2.25and 2.43 kg/m^3.

Table 4.1 Unit weight of various mixes

Mix	**Unit weight (Kg/m^3)**
F(0)S(0)	2.460
F(15)S(0)	2.420
F(30)S(0)	2.415
F(0)S(5)	2.359
F(0)S(10)	2.290
F(15)S(5)	2.430
F(30)S(5)	2.266
F(15)S(10)	2.310
F(30)S(10)	2.256

4.3 COMPRESSIVE STRENGTH

Compressive strength study was carried out on 50mm x 50mm x 50mm cube specimens at the ages of 7, 28, 56 and 90 days. Three specimens were tested at specified ages for all mixes. Table 4.2 shows the compressive strength values of all the nine mixes at different test ages.

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Table 4.2 Compressive strength of different mixes

Mix	Cube Compressive strength N/mm^2			
	7 days	28 days	56 days	90 days
F(0)S(0)	23.20	32.70	40.80	42.00
F(15)S(0)	23.73	36.00	42.70	44.00
F(30)S(0)	21.60	30.80	37.06	37.07
F(0)S(5)	24.30	34.40	41.80	43.70
F(0)S(10)	24.92	34.90	42.60	44.1
F(15)S(5)	22.93	33.20	36.00	37.33
F(30)S(5)	22.67	32.46	35.47	37.20
F(15)S(10)	20.00	37.20	44.00	48.00
F(30)S(10)	18.13	35.02	37.33	38.40

4.2.1 Compressive Strength of Binary Mixes

a) OPC + FA mix

Fig 4.3 shows the compressive strength variationof control mix and binary blends of fly ash and ordinary Portland cement. From the figure it can be seen that fly ash improves the strength at low replacement level and at later ages. F (15)S(0) mix with 15% fly ash, gives better strength than the OPC mix. It may be due to the filler effect and pozzolanic reaction of fly ash. But the increase in strength of F(15)S(0) mix over control mix is significant at later ages only (28 days onwards). It may be attributed to the fact that, the pozzolanic reaction of fly ash is a slow process and hence its contribution to strength development occurs only at later ages.

When the fly ash content is increased to 30% in F (30)S(0) mix, the strength decreases and it is lower than the control mix. It may be due to the fact that at higher replacement levels Portland cement content level will be less which in turn reduces the amount of C-S-H gel resulting from the hydration of ordinary Portland cement.

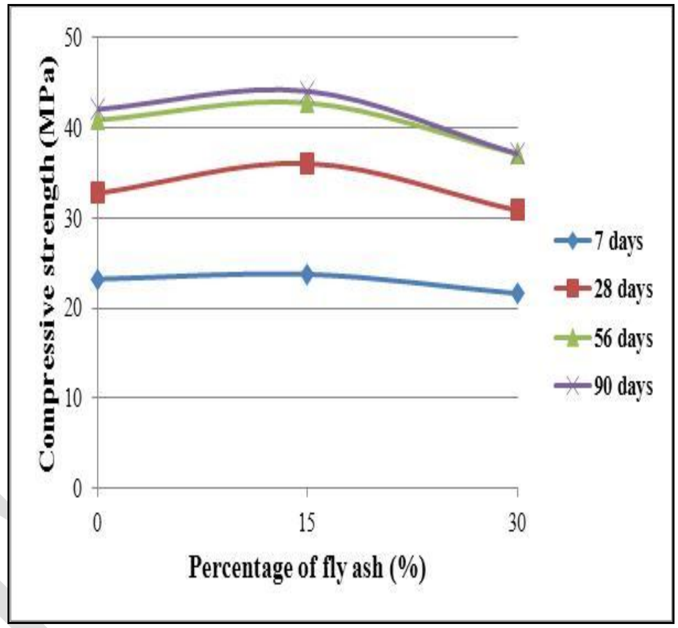

Fig 4.3 Compressive strength development of control and OPC+FA mixes

b) OPC+SF mix

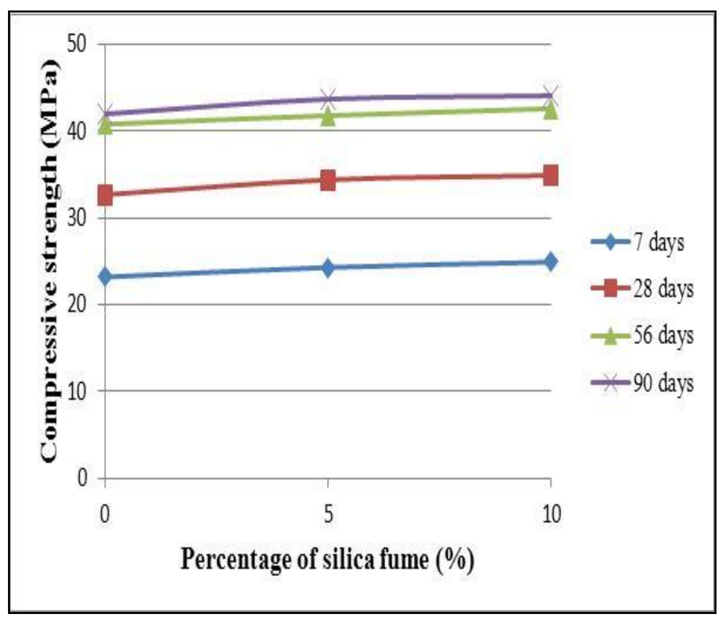

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Fig 4.4 Compressive strength development of control and OPC+SF mixes

4.2.2 Compressive strength of ternary mixes

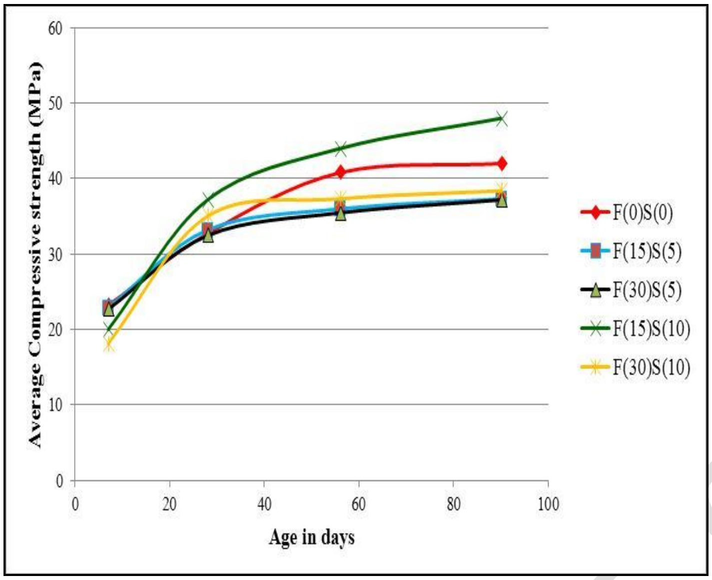

Fig 4.5 Compressive strength development of control and ternary mixes

4.3 FLEXURAL STRENGTH

Beam specimens of size 40mm x 40mm x 160 mm were tested for determining the flexural strength of the nine mixes.Fig 4.7 shows the variation of flexural strength for all the mixes. From the figure it can be seen that all the ternary mixes gives superior performance when compared to the control and binary mixes. It may be due to the filler effect and increased pozzolanic action by the addition of silica fume and fly ash. Maximum flexural strength of 12.85MPa is obtained for mix F(15)S(10).From the figure it is evident that better performance of ternary mixes is evident at later ages, because the pozzolanic reaction of fly ash is a slow process and hence its contribution to strength development occurs only at later ages.

Fig 4.8 shows the rate of strength development in different mixes. From the Fig 4.8 it can be clearly seen that rate of strength development in ternary mixes is greater than the control and binary mixes, and maximum value is obtained for F (15)S(10).

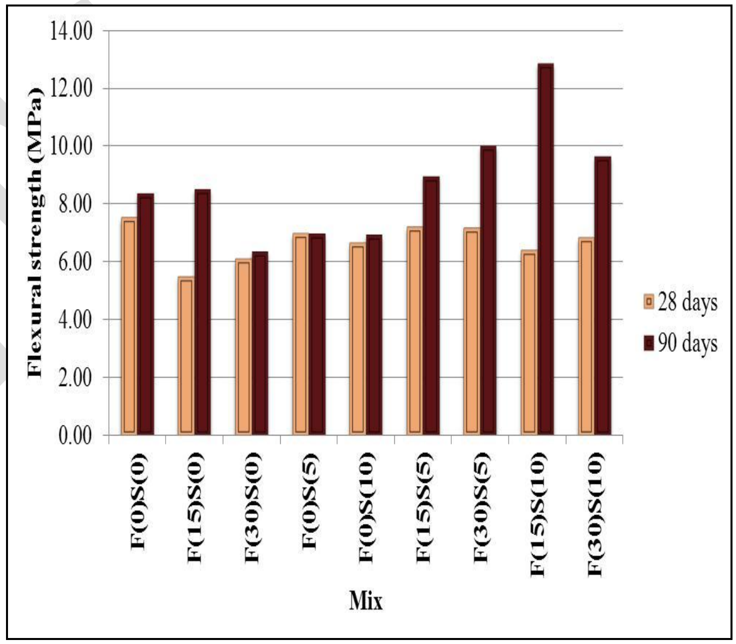

Fig 4.7Flexural strength of various mixes

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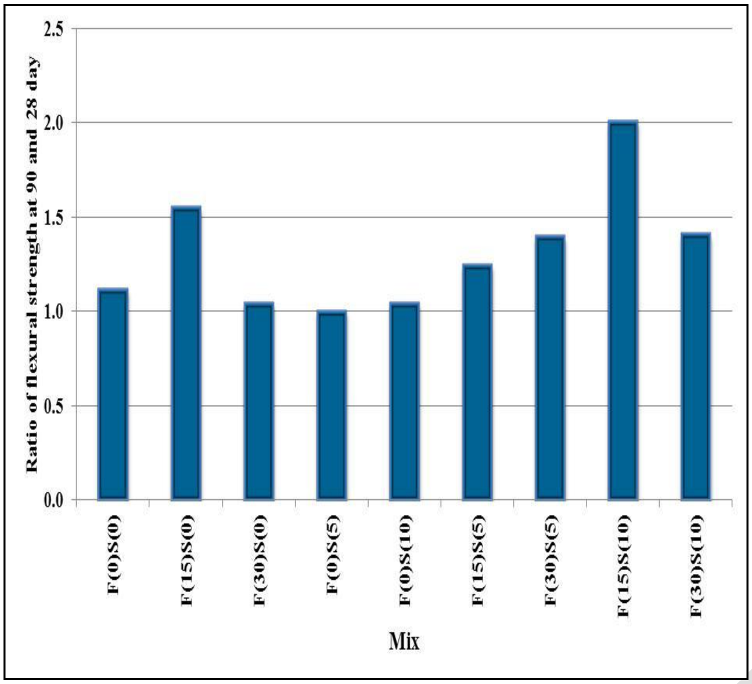

Fig 4.8Rate of increase in flexural strength with age

4.4 SULPHATE ATTACK TEST

The resistance of mortar specimens against sulphate attack was determined on cube specimens of size 50mm x 50mm x50mm, immersed in sulphate solution. After exposure to sulphate solution, white patches were found on the surface of mortarspecimens. The compressive strength variation of the specimens subjected to sulphate attack is as shown by Fig 4.9, Fig 4.10 and Fig 4.11. From Fig 4.9it can be seen that compressive strength of sulphate cured samples increases as fly ash content increases. Similarly from Fig 4.10 it is seen that an increase in silica fume content results in increase in compressive strength of sulphate cured samples. From Fig 4.11 it can be seen that all the ternary mixes show better sulphate resistance when compared to the OPC control mix.

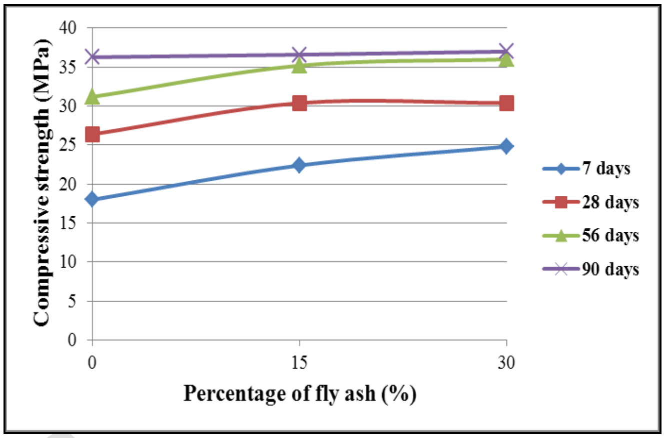

Fig 4.9 Compressive strength development of control and OPC+FA mixes subjected to sulphate attack

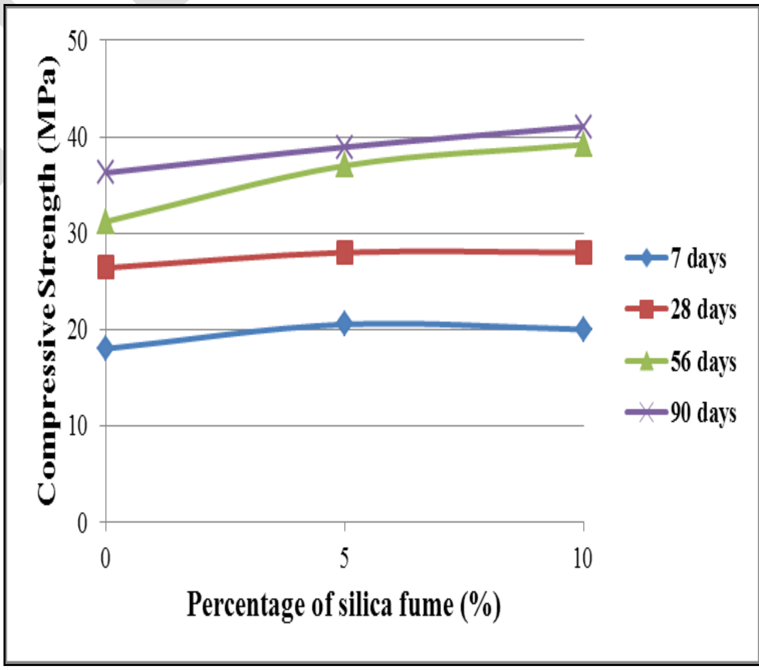

Fig 4.10 Compressive strength development of control and OPC+SF mixes subjected to sulphate attack

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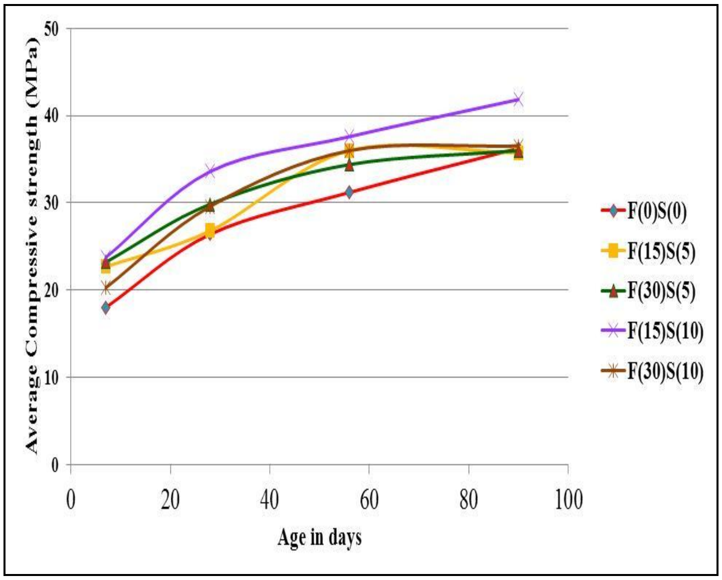

Fig 4.11Compressive strength of control and ternary mixes subjected to sulphate attack

The reduction of compressive strength due to acid attack was expressed in the form of strength deterioration factor (SDF).Fig 4.12 shows the SDF of different mixes when immersed in sulphate solution for 90 days.The results indicate that at higher levels of fly ash, strength deterioration under sulphate attack is less. It mayalso be noted that SDF value of all ternary mixes were less than the control mix. This higher resistance to sulphate attack might be because of the dense impermeable nature of the ternary mixes, due to the reduction of micro pores in the matrix on the addition of FA and SF. The binary mix F(30)S(0) suffers minimum strength loss when subjected to sulphate attack.

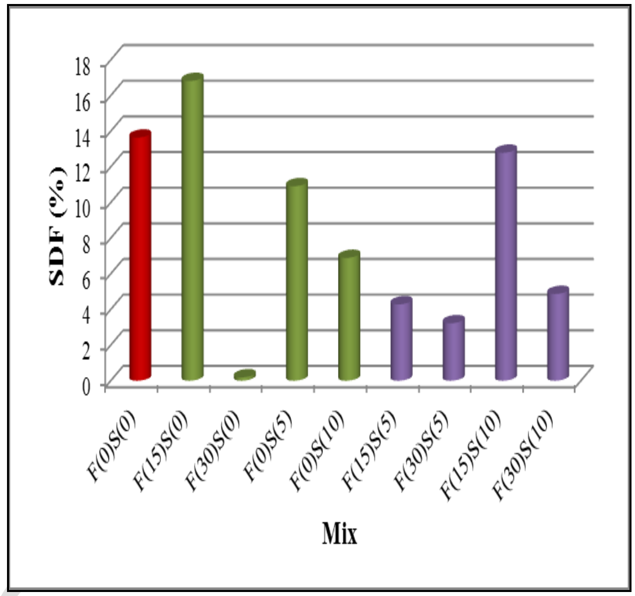

Fig 4.12 SDF values for various mixes when subjected to sulphate attack

4.5 SULPHURIC ACID ATTACK TEST

Table 4.4 shows the compressive strength of different mixes subjected to sulphuric acid attack. Fig 4.13 shows the compressive strength of control and binary mix containing fly ash after sulphate exposure. From the figure it can be seen that at 7, 28 and 56 days there is no commendable increase or decrease in the compressive strength with the addition of fly ash i.e. Binary blends give almost same result as that of OPC control mix. This may be due to the slow reaction rate of fly ash. At 90 days, mix with 15% fly ash shows better acid resistance when compared to the control mix; it may be attributed to the reduced permeability due to the addition of fly ash. But when fly ash content is increased further to 30% the strength decreases. This reduction in strength at 30% fly ash content may be due to deficiency of ordinary Portland cement in the mix.

Fig 4.14 shows the compressive strength development of control mix and binary blends of OPC and SF. From the figure it can be seen that incorporation of silica fume does not improve the acid resistance. When subjected to acid attack the binary blends of silica fume showed reduced strength when compared to OPC mix. Fig 4.15 shows the behavior of ternary blends under acid attack. It can be seen that at later ages (56 days onwards) ternary mix F(15)S(10) showed better acid resistance than the control mix. All other ternary mixes showed poor acid resistance when compared to the control mix.

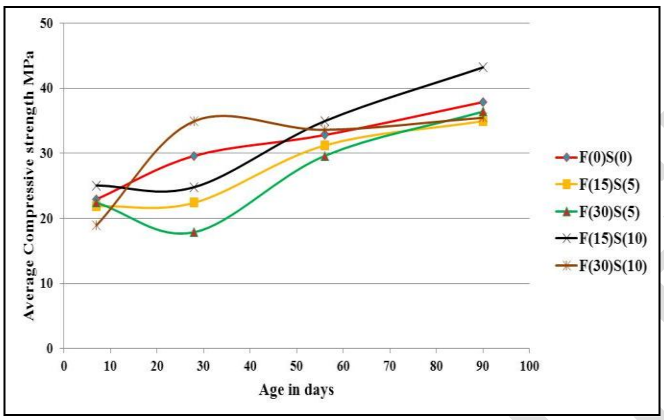

Fig 4.15Compressive strength of control and ternary mixes subjected to acid attack

The reduction of compressive strength due to acid attack was expressed in the form of strengthdeterioration factor (SDF).Fig 4.16 shows the SDF of different mixes when immersed in acid solution for 90 days. It may be noted that the binary mix F(15)S(0) suffers minimum strength loss when subjected to sulphuric acid attack. The SDF value of all ternary mixes was less than the control mix. This higher resistance to sulphate attack might be due to reduced permeability of ternary mixes due to denser microstructure. It may also be noted that binary blends of SF suffered maximum strength loss.

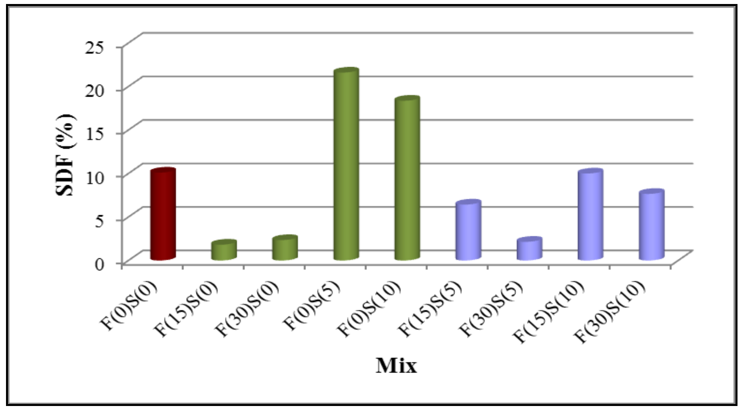

Fig 4.16 SDF values for various mixes when subjected to sulphuric acid attack

4.6 Rapid Chloride Permeability Test (RCPT)

Fig 4.19 shows the variation of total charge passed in different mixes. It may be noted that ternary blends showed higher resistance to chloride ion penetration when compared to both control and binary mixes. Highest amount of charge is passed through control mix and least charge is passed through ternary blend F(30)S(10) mix. Thus the results clearly indicate that addition of fly ash and silica fume in mortar mixes reduces the chloride permeability. The reduced charge in the ternary and binary blends may be attributed to finer pore sixe distribution when compared to control mix. This results in decreased capillary porosity, which in turn increases resistance against chloride ion penetration.

4.7 SORPTIVITY TEST

Sorptivity test was conducted on 100mm x 50mm disc specimens after 28 days of water curing, as explained in the previous chapter. Absorption of water (I) by all the mixes, in the first six hours was measured. Absorption measurements are then plotted as a function of square root of time. Sorptivity is taken as the slope of the curve (I vs.√t) during first six hours. The sorptivity values of all the nine mixes are presented in Table 4.6.

Thus the results indicate that inclusion of fly ash and silica fume reduces the water absorption of mortar specimens. This may be due to the filler effect of fine fly ash and silica fume particles, which makes the water passage harder. When fly ash and silica fume are added particles pack more tightly with lesser voids, thereby reducing permeability and sorptivity.

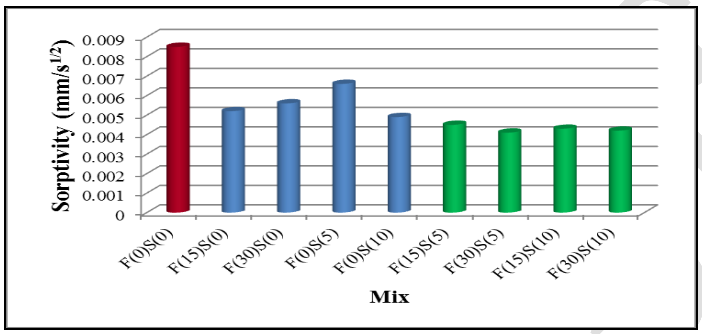

Fig 4.21Sorptivity of various mixes

4.8 QUANTIFICATION OF SYNERGY

The theoretical values of the strength and durability properties of ternary mixes were calculated using the equation described in the previous chapter and the magnitude of synergistic effect (S.E) was calculated using the equation:

$$S.E = j \times \left(\frac{P_{actual} - P_{theor}}{P_{theor}}\right) \times 100$$

Where SE is the synergistic effect (%), P_{actual} is a measured value of a given property, $P_{theor}$is a theoretical value of a given property and j = 1 for properties to be maximized (compressive strength) and j = -1 for properties to be minimized (rapid chloride permeability and initial sorptivity).

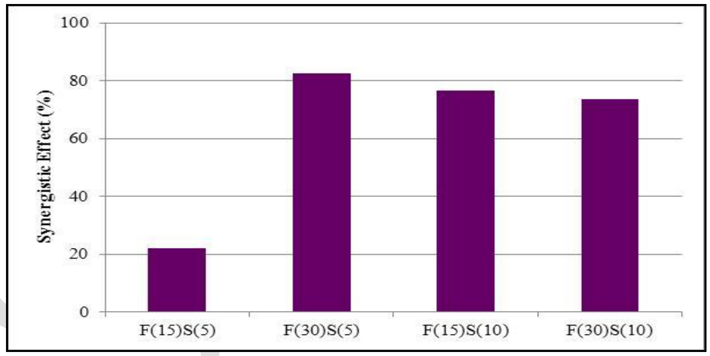

Fig 4.23Synergistic Effect Vs Mix for 90 days Flexural strength

Figure 4.24 shows the synergistic effect in the development of 90 days compressive strength of the ternary blends subjected to sulphate attack and acid attack. It can be seen that when the ternary mixes were subjected to sulphate attack only mix F(15)S(10) showed positive synergy. Under acid attack all the ternary mixes except F(15)S(5) showed positive synergy.

CONCLUSION

5. CONCLUSIONS

Test results have shown that the ternaryblended mixtures overall improved the mortar performance by improving the workability, strength and durability, therefore are applicable. Ternary mixtures overall performed in accordance with their ingredients; however the degree of improvement that they contribute varies based on the selected dosage and type of SCMs. The following conclusions are made based on the results:

- At constant water binder ratio, superplasticiser demand decreases with increase in fly ash content and increases with increase in silica fume content, i.e. fly ash improves workability and silica fume decreases workability.
- Maximum dry unit weight is obtained for control mix. The unit weight of the mortars with binary and ternary blends decreased with an increase in FA and SF content.
- Fly ash improves the compressive strength only at low replacement level and at later ages.
- Increase in silica fume content increases compressive strength at all ages.
- Maximum compressive strength was obtained for ternary mix F(15)S(10). It showed a 14.3% increase in 90 days compressive strength when compared to control mix.
- When the cement replacement level is increased beyond 25%, compressive strength decreases.
- All ternary mixes showed better flexural strength when compared to control and binary mixes. Maximum flexural strength was obtained for ternary mix F(15)S(10).
- Increase in fly ash content and silica fume content increases the compressive strength of mortar specimens subjected to sulphate attack.
- Under sulphate attack all ternary blends outperformed control mix, they suffered minimum strength deterioration when compared to control mix. Maximum compressive strength was obtained for F(15)S(10) mix.

5.3 SCOPE FOR FUTURE WORKS

- Effect of variation in mix composition can be studied by changing the fly ash content and the silica fume content.
- Effect of variation of water binder ratio on the strength and durability properties of ternary blends may be studied.
- Additional tests may be conducted to determine the effect of ternary blending on carbonation rate.
- The investigation may be extended to ternary blending of ordinary Portland cement, fly ash and silica fume in concrete.
- Petrographical study on the mineral formation of different ternary blends during hydration may be studied.
- The effect of quaternary blends on strength and durability parameters can be investigated.

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