EXPERIMENTAL STUDY OF DURABILITY OF MORTAR USING ALTERNATIVE BUILDING MATERIAL

Thesis submitted to Faculty of Engineering and Technology, Jadavpur University

In the partial fulfillment of the requirements for the degree of

MASTERS OF CONSTRUCTION ENGINEERING

With specialization
In

STRUCTURAL REPAIR AND RETROFIT ENGINEERING
By

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May, 2019

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that the thesis entitled "**EXPERIMENTAL STUDY OF DURABILITY OF MORTAR USING ALTERNATIVE BUILDING MATERIAL**" *contains literature survey and original research work done by the undersigned candidate , and have been submitted for the partial fulfillment of the Continuous assessment of the course of Master* of Construction Engineering, *specialization in* "**Structural Repair and Retrofit Engineering**" *of* Jadavpur University.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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ACKNOWLEDGEMENT

First and foremost, I would like to thank **Dr. Partha Ghosh**, Associate Professor, Department of Construction Engineering, and Jadavpur University for his utmost support and being always available to help me with all my doubts and queries and financially as well. His immense patience and valuable guidance has helped me in completing my thesis work. I am very much grate full for having opportunity to work under his kind supervision which has enriched me a lot which will be very useful in my future career.

I am very grateful to **Dr. Kushal Ghosh**, presently attached to National Institute of Technology, Sikkim as Assistant Professor Department of Civil Engineering for his consistent support to carry out this thesis work, without whose guidance it was perhaps impossible to complete my thesis work.

I would also like to give special thanks to **Dr. Debasish Bandyopadhyay**, Head, Department of Construction Engineering, Jadavpur University for giving me the encouragement while doing this thesis work.

I am also thankful to the staff members of repair and retrofit laboratory, especially to Mr. Tarak Ghosh for providing necessary help and resources to complete my experimental evaluation works.

The past few years have been a good learning experience at Jadavpur University I will take this opportunity to thank my friends here at Jadavpur University, who in some way or other have helped me in my journey.

Finally and most importantly, I thank to my parents for believing in me and keeping me focused in both happy and tough times in my life and has sacrificed a lot for me. I would not have reached here so far without their support. I dedicate this thesis to them.

(SANTANU MONDAL)

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ABBREVIATION & SYMBOLS USED

OPC: - Ordinary Portland cement

FA:-Fly Ash

SF: - Silica Fume

AF: - Alccofine

GGBFS:-Ground Granulated Blast Furnace Slag

SCM: - Supplementary cementitious material

XRD:-X-ray diffraction

C-S-H: - Calcium silicate hydrate

OPCC:-Ordinary Portland cement concrete

OPC: - Ordinary Portland Cement

SEM: - Scanning Electron Microscopy

EDS: - Energy-dispersive X-ray spectroscopy

ABSTRACT

With the increase of urbanization and rapid growing industrialization, the need for sustainable building materials is rising. Ordinary Portland cement, which functions as the key binding agent in concrete has a manufacturing process which liberates huge amount of CO_2in to the atmosphere(approximately 1 tonne of OPC production liberates 1 tonne of CO_2). The manufacturing process of OPC involves the usage of a large amount of limestone, which also results in the depletion of natural resources almost1.5 tonne [5] of natural resources needed for production of 1 tonne of OPC. Also use of OPC leads to some durability issues when the concrete is exposed against acid and sulphate exposure.

The key objective of this research work is to evaluate the optimum percentage of mineral admixtures, used as supplementary cementitious materials and additives which can overcome those shortcomings of OPC without compromising on compressive strength. In our case we have used flyash, alccofine 1203 and Silica fume as supplementary cementitious materials. Effort has been made to improve the fresh as well as hardened property of concrete with the inclusions of the above mentioned mineral admixtures. Total 273 no's of sample of 50mmx50mmx50mm cube samples have been casted. Flow table test as well as initial and final setting time has been conducted to compare the improvement if any with respect to OPC. To investigate hardened property in unexposed conditions, 7 days and 28 days compressive strength, water absorption, apparent porosity, bulk density, and sorptivity test has been conducted conforming to the relevant IS and ASTM codes of practice. Durability characteristics of 50mmx50mmx50mm mortar cubes sample were tested by exposing them to 4% sulphuric and 4% $MgSO_4$solution for 56 days, as well as exposing them to elevated temperature (400°C, 600°C, 800°C) for 4 hours. Their weight loss in various exposure conditions and residual strength has also been studied. Also the morphological changes of the various samples exposed to different exposure conditions, at microstructural level, were also observed through Scanning electron microscopy and their chemical compositions of were observed through Energy dispersive X-ray analysis. Development in C-S-H gel matrix, formation of inner hydration product like calcium hydroxide, gypsum, and ettringite were observed at a microstructural level through these tests. From the experimental results it may be concluded that inclusion of Silicafume

results in the greater increase of compressive strength in comparison to Alccofine. 30% Flyash and 10% Silicafume combinations gave the best value of compressive strength of 54 Mpa. In case of acid exposure best performing samples are C70FA30AF15 and C50FA50SF10 respectively. For sulphate exposure samples, the ones containing Alccofine and Silicafume in the range of 5 to 15% with 50% flyash combinations showed better results in terms of weight loss and residual strength. There is not much improvement observed for the sample exposed to elevated temperature with the inclusions of mineral admixtures.

CHAPTER I INTRODUCTION

1.1GENERAL

Conventional construction materials such as bricks, hollow bricks, cement, sand, and pavement blocks are the production of natural resources, which causes depletion of limited natural resources, emissions of various harmful green house gases like carbon monoxide, oxides of sulfur, carbon dioxide in massive quantity during their manufacturing process. There liberation to environment causes contamination of air, water, soil, flaura and fauna and aquatic bio diversity which is a serious threat to human and animal life. Furthermore replacement of cement by any of the industrial by product like flyash, blast furnace slag, metakeoline etc [5] only by 5% of weight of cement reduces $75x10^6$ tonne of Carbon dioxide(Considering a world production of about $1500x10^6$ t/year with emission of an average 1 kg CO_2/kg cement) emissions. Also cost of construction materials are increasing day by day due to extensive demand of urbanization and limitation of natural resources and energy savings.

There by attention had been drawn towards sustainable concrete which will meet the need for present without hampering the scope of future generation. The present study is based on the investigation of performance of ternary blended cement mortar prepared with flyash as a partial replacement to the ordinary Portland cement and alccofine and Silicafume as additives under various exposure conditions like Sulphuric acid(H_2SO_4), Magnesium Sulphate($MgSO_4$) and thermal exposure, and improvement if any due to inclusion of those mineral admixture in hardened property like compressive strength, fresh property like workability, water absorption and porosity etc.

Also inclusions of additives may improve the morphological structure of the concrete evident form SEM (Scanning electron microscopy) and EDS (Energy dispersive spectroscopy) analysis by improving the C-S-H gel matrix of the mix. This can represent a major breakthrough for the concrete industry by offering opportunities for new cementitious materials produced from various by-products of thermal and steel industries due to reduction of cost of cementitious materials and from the standpoint of energy saving and conservation of natural resource. In our present course of study its attempted to find the most critical combinations of the mix from strength and durability point of view that specimen exposed to acid, salt and elevated temperature.

1.2 ALTERNATIVE BUILDING MATERIALS USED:-

While the world has come to rely on concrete as one of the main material for building construction, concrete could actually harm the environment more than it is helping. To illustrate, 16% of all fossil fuel consumed every year is used to turn those raw materials into construction products.

In regards to this, here are some several green alternatives for building material which can give a lower impact on the environment, may curtail the cost of production of concrete, which may be used as partial replacement to the ordinary Portland cement or additives.

- Fly ash
- Ground granulated blast furnace slag(GGBS)
- Alccofine
- Silica fume
- Carbon nano tube(CNT)
- Graphene oxide(GO)
- Rice Husk
- Metakeoline

Among few new aged alternative building materials specified above in our studies, we have used Fly ash as partial replacement to the ordinary Portland cement, Alccofine, and Silica fume as additives.

1.3 Fly ash as alternative material:-

Once upon a time it was an environmental pollutant, but now the situation has changed and it has become a supplementary cementitious material used for the purpose of construction materials. Flyash is one of the residues generated during construction of coal and comprises the fine particles that rise with the flue gases, generally captured by electrostatic precipitators or the other particle filtration equipments before the flue gases reach the chimneys of coal fired power plants. Depending upon the source of the coal being burned, the components of flyash vary considerably, but all flyash includes substantial amount of silicon dioxide (SiO_2) both amorphous and crystalline and calcium dioxide (CaO) both being endemic ingredients in many coal bearing rock strata. Growth of population, increasing urbanization, and rising standards of living due to technological innovations have contributed to increase the quantity of a variety of solid wastes generated by industrial, mining, domestic and agricultural activities. The disposal of fly ash from coal-fired power stations causes significant economic and environmental problems. A relatively small percentage of the material finds application as an ingredient in cement and other construction products, but the vast majority of material generated each year is held in ash dams or similar dumps. This unproductive use of land and the associated long-term financial burden of maintenance have led to realization that alternative uses for fly ash as a value-added product beyond incorporation in construction materials are needed. Utilization of fly ash in such areas as novel materials, waste management, recovery of metals and agriculture is reviewed in this article with the aim of looking at new areas that will expand the positive reuse of fly ash, thereby helping to reduce the environmental and economic impacts of disposal.

1.4 Silica fume as alternative material:-

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production.

Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor. Silicon metal and alloys are produced in electric furnaces as shown in this photo. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being land filled. Perhaps the most important use of this material is as a mineral admixture in concrete.

Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolan when used in concrete. The quality of silica fume is specified by **ASTM C 1240** and **AASHTO M 307**.

Silica fume is produced when SiO vapors, produced from the reduction of quartz to silicon, condense; contain approximately 90% silicon dioxide with traces of iron, magnesium, and alkali oxides.

1.5 Alccofine as alternative material:-

Alccofine is a specially processed slag based product of high glass content, prepared by the method of controlled granulation. The purpose of using alccofine are versatile in nature i.e. maybe use as water reducer to prepare high strength high performance concrete, also to replace cement in production of concrete. Alccofine 1203 is a low calcium slag based silicate which having fine, micro fine and ultrafine particle size distribution. Alccofine 1203 is having a property of reducing water demand for a particular workability requirement, even up to 70% replacement level.

2.1 GENERAL

Cement concrete is the most widely used construction materials around the globe, properly designed and manufactured concrete are very much effective from durability and strength point of view but there has certain limitations as well as its production liberated green house gases to the climate. Also concrete is inadequate to perform better in special situations. Hence the requirements of various mineral admixtures like Flyash, Silicafume, alccofine, metakeoline, Rice husk etc has come into platform as partial replacement of ordinary Portland cement. Blended cement leads to high performance concrete which appears to be high strength and durable as well. From the past few decades production of Portland cement is a matter of concern from global point of view, as 1t of Portland cement production produces almost 1t of CO_2 to the environment, causing decreasing trends of manufacturing of ordinary Portland cement worldwide in view of the popularity of blended cement, because of the consumption of low energy, environmental pollution, economic and other technical reasons. In this section we would generally discuss about the various literature reviewed during the entire course of thesis work.

[11]Sarfaraz Ahamed, Kagadgar has investigated the durable properties of blended concrete replaced with flyash from 0 to 60% and with a constant amount of alccofine 5% by weight of the cementitious materials. It is reported that inclusion of alccofine and high quantity of flyash resulted in high workability of concrete.[19] Alccofine gains early strength where as flyash has slower strength gaining properties. 5% alccofine, 15% flyash combination reported best result from compressive strength point of view, from durability study it has been observed that with increase of flyash content it resulted lower permeability and lesser corrosion density.

[15]Tushar shirke, A.shinde has studied the durable performance concrete partially replaced by fly ash and alccofine for M_{20} grade concrete. It has been observed that compressive strength of concrete is increasing up to 20% alccofine replaced with ordinary Portland cement after that it is decreasing trend has observed.

[25]Ch. Venugopal Reddy, T.L Ramadasu concluded in their study that addition of silica fume to Portland cement paste or concrete improves strength development of Portland cement mix because of the reason pore size refinement and matrix densification. The material which contains more than 80% silica in non crystalline state in the form of extremely fine particles is highly pozzolanic. In their study it's observed that 10, 20 and 30% replacement were made by weight of the cement and maximum compressive strength were achieved by 15% replacement of cement with silica fume.

[9]Alccofine 1203 is low calcium silicate, alccofine 1200 series e.g. 1201, 1202, 1203 represents fine, micro fine, ultrafine particle. Alccofine 1203 based on slag of high glass content with high reactivity obtained through the process of control granulation.[19] It provides reduce water demand, for a given workability. The main advantages of using mineral admixture are lesser consumption of cement content and lesser generation of heat of hydration.

[26]Siddharth P.Upadhay and M.A.Jamuna has studied compressive strength of concrete have been investigated for control mix and mix content alccofine 4%, 6%, 8%, 10% and 12% as Portland cement replacement and 30% fly ash of constant percentage as replacement of cement. M_{60} grade of concrete were designed and maximum compressive strength achieved by using alccofine 10% and fly ash 30% combinations. [3]Alccofine gains high early strength, in this investigation its observed all mix proportions gains strength up to 3 days good, between 3 to 7 days its average. Compressive strength at 28 days for w/c 0.5 ratio gives 73.8 MPa.

[10] A.parmar, D.M.Patel and other has suggested in their investigation on blended concrete where cementitious material has been replaced by alccofine in the range of 4 to 14% and fly ash in the range of 20 to 29%. Optimum dosage of alccofine and fly ash found to be 8% and 20% respectively. Blended concrete prepared with alccofine

is more durable than control concrete due to pozzolanic action of alccofine leading to pore refinement and denser concrete matrix. Few findings of this paper are elaborated as follows:-

Sorptivity of silica fume sample is more than alccofine sample so capillary rise is more in silica fume.

Silica fume sample affected more in corrosion test than alccofine sample.

Strength loss (avg) for silica fume sample is more than alccofine for 28 days and 56 days.

From alkali attack test alccofine perform better than silica fume.

From sulphate attack alccofine perform better than silica fume from weight loss and strength loss point of view.

From sea water test result it can be concluded that alccofine performs better than Silicafume.

[1] Ji Yajun and Jing Herman reported in their study Silicafume improves pore structure in two ways, its small particle size results in a filler effect in which the particles acts as bridge between the space of cement grains and aggregates, it reacts pozzolanically with $Ca(OH)_2$ and produce denser C-S-H gel, leading to fill up of pore spaces during hydration. It has been observe the Silicafume blended mix gaining strength very slow even up to 28 days, it become obvious at later ages (i.e. 56 and 90 days), resulting compressive strength of blended cement paste not significantly increased up to 28 days due to agglomerate, which cannot be broken down by control mix.

[2] P.Murthy and V.Sivakumar has reported in their study ordinary Portland cement is not performing good against acid exposure, the addition of flyash improves the micro structural and physical properties of concrete like porosity, permeability and sorptivity, which thereby improves in chemical attack and corrosion resisting properties , although inclusion of fly ash in concrete appears to be slow gaining of strength with age , although this short comings may be avoided by introducing Silicafume like ultrafine materials to concrete along with this binary mix. The

development of binary blended concrete with 20% replacement level reduces the mass losses considerably while exposed to H_2SO_4. The ternary blended concrete with 20% flyash and 8% Silicafume shows very good resistance in sulphuric acid exposure. The development of ternary blended concrete with the optimum replacement levels shows the reduction of secondary unstable ettringite and reduces the acid attack considerably.

[3] J.E Rossen and B.L.Lothenbach has observed in their study on composition of C-S-H in pastes, that in the range of temperatures plain cements shows relatively low impact for some degrees of hydration in comparison to concrete containing Silicafume in plain cements some densification of C-S-H and coarsening of the porosity has been observed.

[4] Sidney diamond reported in his paper regarding micro structural study that a finer polish and a conductive coating are needed. It was previously presumed that drying sample preparation may change the C-S-H nano scale structure, but such change occurs it may not detectable in back scatter mode of Scanning electron microscopy. A hydration shell that represents fully complete hydration. Actually that is not conform that a grain that appears fully hydrated on the plane of observation is in fact completely hydrated, there may be a residual anhydrate core exiting above or below the plane being imaged.

[5] M.saad, G.B.Hanna and others have reported in their study that addition of Silicafume causes improvement of physical, mechanical and durable properties of concrete due to its physical effects, which fill the space between cement particles due to its fineness, and chemical reaction of Silicafume with hydrated product, because of high surface area and high content of amorphous silica. Therefore the following conclusions we may derived from the study that addition of Silicafume to Ordinary Portland Cement causes consumption of $Ca(OH)_2$ which is a hydration product. 10% Silicafume possess lower porosity at temperature level of 600°C and highest compressive strength.

[14] T.Kala Deepthi has elaborated in their durability study of blended concrete that inclusion of Silicafume results in improvement in temperature resistance with less loss of weight as calcium hydroxide converted to calcium silicate compound which is stable product performing much better under elevated temperature.

[7] Thanongsak Nochaiya, Watcharapong Wongkeo has reported in their study that geopolymer , flyash and Silicafume contains high amount of Al and Si compounds with reaction with $Ca(OH)_2$ formed more stable C-A-S-H with high filler effect resulted in less weight loss in acid exposure. Depletion of compressive strength of Silicafume blended concrete compound to control mix is less particularly for 20% replacement level is low, for 2% H_2SO_4 exposure for 90 days.
The serviceability of Portland cement concrete can be severely shortened in the acid exposure because of reaction of calcium compounds presents in the concrete.

[8] S.P.Zhang and L.Zong has reported in their study of durability of concrete mainly depends on capacity of fluid to penetrate concrete's microstructure, called permeability. Mineral admixture required a long curing period relatively for the favorable pozzolanic effect on performance of the concrete to be realized. More over low permeability of concrete can improve resistance to the penetration of water, Sulphate ions, chloride ions, alkali ions and other harmful substances which caused chemical attack. Pore structure mainly involved volume and sized of the inter connected capillary pores The pore network of a concrete paste matrix provides passage for the transport of fluid into the concrete and its development depends on a number of factors, including properties and compositions of the concrete constituents materials. The initial curing conditions, its duration, the age at testing and the climate exposure it's drying and conditions of concrete. Strength cannot be related merely by water absorption. Higher water absorptions reduces resistance to sulphte attack, there relations are linear approximately.

[24]Y.Senhadji and G.Escadeinas has reported in their study that it's possible to improve acid resistance of mortar using natural pozzolan, but different rates of performance depends upon the various proportions of pozzolanes, but mortar produce with Silicafume may severely damage sample exposed to Sulphuric Acid environment.[23] Supplementary cementitious materials contain silica in amorphous form, which would react with portlandite to form more stable C-S-H gel, which will further improve concrete strength .[16] Silicafume significantly reduce internal porosity of the mix and improved its compressive strength as well, but it is may not be able to perform well in highly concentrated Sulphuric acid exposure, as a matter of fact it may therefore be attributed to the fact that converting C-H or portlandite into C-S-H gel and filling the pore network does not assured the better performance in acidic environment.

[28] J.Prasad and D.K.Jain has investigated in their study of "Reaction with Sulphate ion with cement hydration product" that Sulphate attack in concrete generally occurs in three modes namely:-

(1) Acidic type, attributed mainly due to formation of Gypsum, leading to formation of cohesion less granular mass.

(2) Deterioration causes due to presence of high concentration of portlandite, causes formation of Ettringite resulting expansion type deterioration of concrete.

(3) Onion peeling type, which mainly due to scaling of the successive concrete layer.

The primary product formed due to acid attack and reaction between sulphte bearing solution and C-S-H gel are Ettringite and Gypsum.[28] Cementitious materials that is low calcium having good sulphate resistance, i.e. less content of C_3A.

[27] R.Demirboga has investigated in his study , addition of mineral admixture e.g Silicafume, Flyash and GGBFS influencing the thermal conductivity of mortar and it has been reported that that, thermal conductivity decreased with increase of mineral admixtures as a replacement of cement, both SF and FA has a decreasing

effect of thermal conductivity with maximum 40% for 30% SF replacement, and its 33% for 30% FA replacement level.

Thermal exposure is susceptible to concrete durability, which causes weight loss, [30] B.Demirel and O.kelestemur studied that unit weight of the concrete mix decreased due to thermal exposure may be due to release of bound water from the cement paste and occurrence of air voids. The decomposition of portlandite and C-S-H gel occurs at 800°C, resulted in deterioration of concrete and decrease in compressive strength.

2.2. OBJECTIVE OF STUDY:-

The main objectives of this thesis are to investigate the following:-

- To compare improvement in fresh property like workability, bulk density, water absorption and apparent porosity with the inclusion as well as blending of additives.
- To study the long term and short term strength gaining property of the geopolymer concrete in terms of 7 days and 28 days compressive strength.
- To study the durability performance of the mix exposed to 4% Sulphuric acid (H_2SO_4) for 56 days in terms of residual compressive strength and weight loss.
- To study the durability performance of the mix exposed to 4% Magnesium Sulphate Solution ($MgSO_4$) for 56 days in terms of residual compressive strength and weight loss.
- To study the performance of the mix under elevated temperature up to 800°C for 4 hours, in terms of residual compressive strength in percentage(%) and weight loss.
- Also to compare performance of the ternary mix made of ordinary Portland cement, Flyash, alccofine and Silicafume respectively in terms of mechanical property, durability and fresh property.
- Finally to find out the optimum percentage of mineral admixtures to produce sustainable concrete will perform best in all respect.

2.3 SCOPE OF WORK:-

In this thesis work our main objective is to find out optimum percentage of Fly ash and additives by comparing fresh, hardened and durable properties. Effort has been made to identify the optimum composition of mix performing better in Sulphuric acid, Magnesium sulphate and thermal exposure conditions.

Study of fresh property e.g. permeability in terms of sorptivity , apparent porosity, bulk density , water absorption, hardened property in terms of compressive strength, durable property of the sample exposed to acidic , sulphate and sample exposed to elevated temperature up to 800ºC.

Study of maximum percentage of replacement of cementitious materials with fly ash.

Study of changes in the mortar paste at micro structural level after 28 days ordinary curing, and sample exposed to acid, sulphate and elevated temperature by Scanning Electron microscopy, at different magnification and resolutions.

Investigation of changes in composition due to production of hydration product of the sample prepared with ordinary Portland cement, flyash, alccofine and Silicafume exposed to various exposure conditions as aforementioned, by Energy-dispersive X-ray spectroscopy (EDS) analysis.

CHAPTER III EXPERIMENTAL INVESTIGATIONS

3.1 GENERAL

Effort have been made to study the feasibility of incorporation of mineral admixtures like flyash, alccofine and Silicafume in our study as partial replacement to the ordinary Portland cement and also as additives to improve the fresh and hardened property of concrete.

3.2 MATERIAL USED

The physical properties of the material used are discussed in the following sections:-

3.2.1 Cement:-

Ordinary Portland cement, under the industrial name (Ultra tech) conforming to IS: 8112:2013 used in the entire course of study. The results of the various tests on physical properties of cement used for the experiment are given below:-

TABLE: 3.1

PHYSICAL PROPERTIES OF CEMENT

SL No.	Physical Characteristics	Units	Test Results	Limits As per IS:8112:1989
1.	Consistency	%	33	-
2.	Initial Setting Time(IST)	Minutes	205	Not less than 30
3.	Final Setting Time(FST)	Minutes	260	Not greater than 600
4.	Specific Gravity	-	3.03	-
5.	Compressive strength(MPa)			-
7 days		MPa	31	Not less than 23
28 days		MPa	54	Not less than 33

Fig 3.1 OPC 43(Ultratech)

3.2.2 Fly ash:-

In India large quantity of fly ash gets produced and becomes available as a byproduct of coal-based power stations. It is a fine powder resulting from the combustion of powdered coal. Partially replacing cement with fly ash a waste converted into a resource material in concrete. Presence of flyash improves mechanical and durable properties of concrete, which also improves workability of concrete by reducing its water demand. Flyash processes very less to no cementitious properties, but in presence of moisture it reacts with calcium hydroxide ($Ca(OH)_2$) to form C-S-H gel which is responsible to development of strength of concrete.

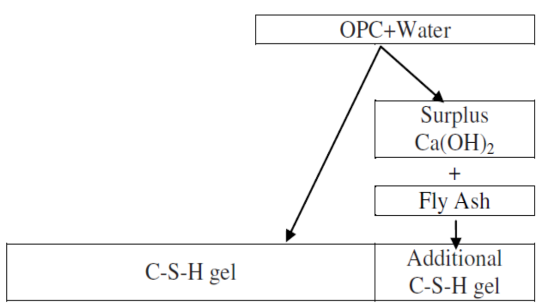


Fig 3.2 Flyash reaction with OPC

Fig 3.3. Fly ash

OPC is a product of four principal mineralogical phases. These phases are

i) Tricalcium Silicate-C_3S ($3CaO.SiO_2$),

ii) Dicalcium Silicate -C_2S ($2CaO.SiO_2$),

iii) Tricalcium Aluminate- C_3A ($3CaO.Al_2O_3$) and

iv) Tetracalcium alumino-ferrite – C_4AF($4CaO.\ Al_2O_3.Fe_2O_3$).

The setting and hardening of the OPC takes place as a result of reaction between these Principal compounds and water.

The reaction between these compounds is as follows:

$$C_3S + H_2O = 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

(C-S-H gel)

$$C_2S + H_2O = (\text{C-S-H gel}) + Ca(OH)_2$$

$$C_3A + H_2O + 3CaSO4.2H_2O = 3CaO.Al_2O_3.3CaSO_4 \cdot 32H_2O$$

(Gypsum) (Ettringite)

Above reactions indicate that during the hydration process of cement, lime is released Out and remains as surplus in the hydrated cement. This surplus lime makes the concrete porous and gives chance to the development of micro- cracks. If fly ash is available in the mix, this surplus lime becomes the source for pozzolanic reaction with fly ash and forms additional C-S-H gel having similar binding properties in the concrete

Addition of Fly Ash to concrete gives several advantages e.g. increases workability, Lowers the heat of hydration, increases strength in compare to OPC at later age, reduces alkali-aggregate reaction, gives more resistance to corrosion of reinforcements etc. Low calcium flyash (Class F) was used in this investigation. In our study we have used flyash having following several properties:-

- Fineness:-400-600 m^2/kg.
- Sp.Gravity:- 2.11-2.14.
- Bulk density: - 1120-1500 kg/m^3.

3.2.2.1 <u>Microstructure analysis of Flyash through SEM:-</u>

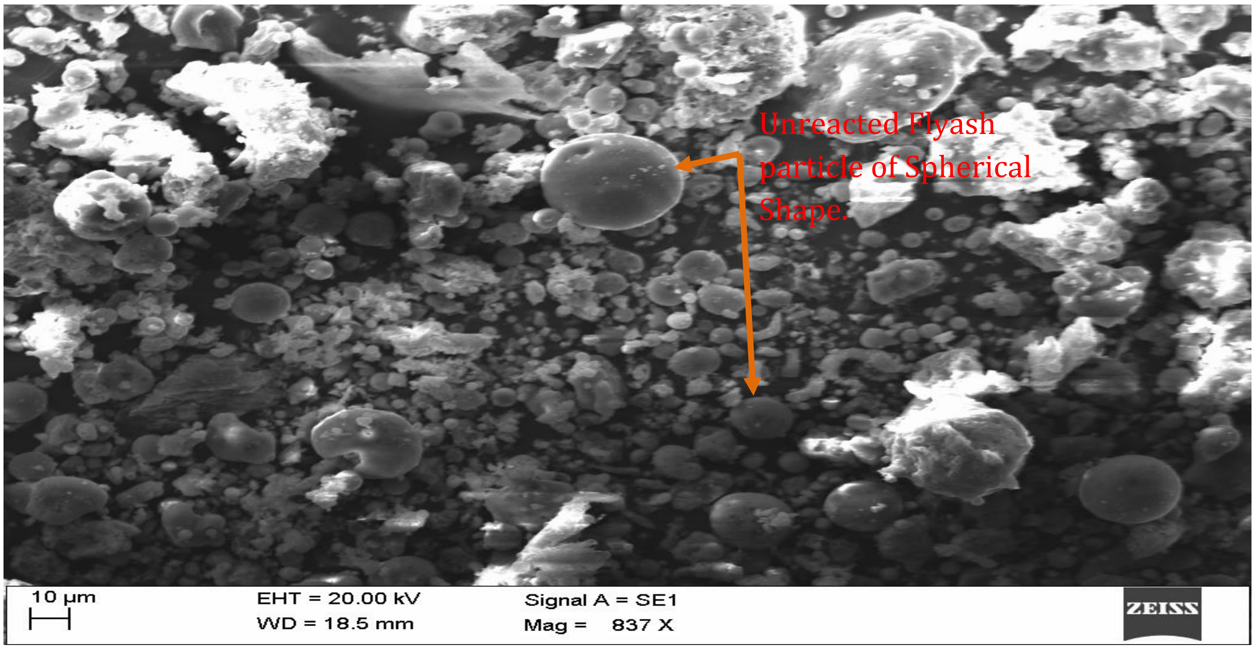


Fig 3.4 SEM image of flyash used for the purpose of the test at 837X.

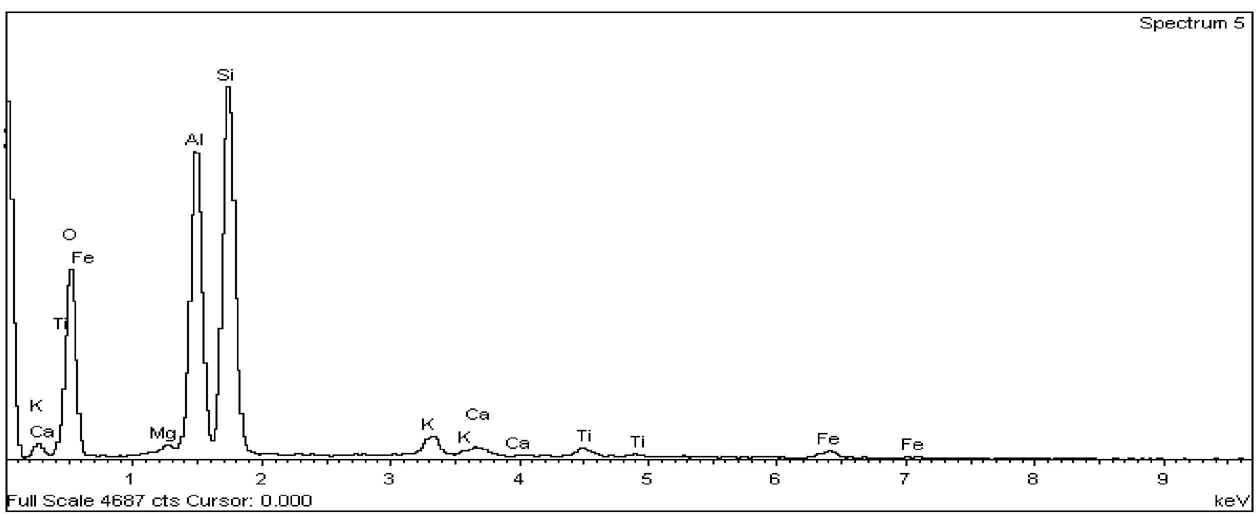


Fig 3.5 EDS Spectrum of Flyash

Table 3.2: EDS results of flyash.

Element	Weight%
O K	48.41
Mg K	0.42
Al K	17.98
Si K	27.71
K K	1.95
Ca K	0.66
Ti K	1.09
Fe K	1.78
Total	100

3.2.3 Alccofine:-

Alccofine is proprietary low calcium silicate based mineral additive. Controlled granulation process results in unique particle size distribution. Its latent hydraulic property and pozzolanic reactivity results in enhanced hydration process. Addition of Alccofine improves the packing density of paste component .This results in lowering water demand, admixture dosage and hence improving strength and durability parameters of concrete at all ages. In our study we used Alccofine 1203 of Ambuja Cement Company. Following are the several properties of alccofine used for the experiment:-

- Fineness:-13000 m^2/kg.
- Sp.Gravity-:-2.7-2.85.
- Bulk density: - 700-900kg/m^3.

Fig 3.6 Alccofine 1203 used for the experiment.

3.2.3.1 <u>Microstructure analysis of Alccofine through SEM:-</u>

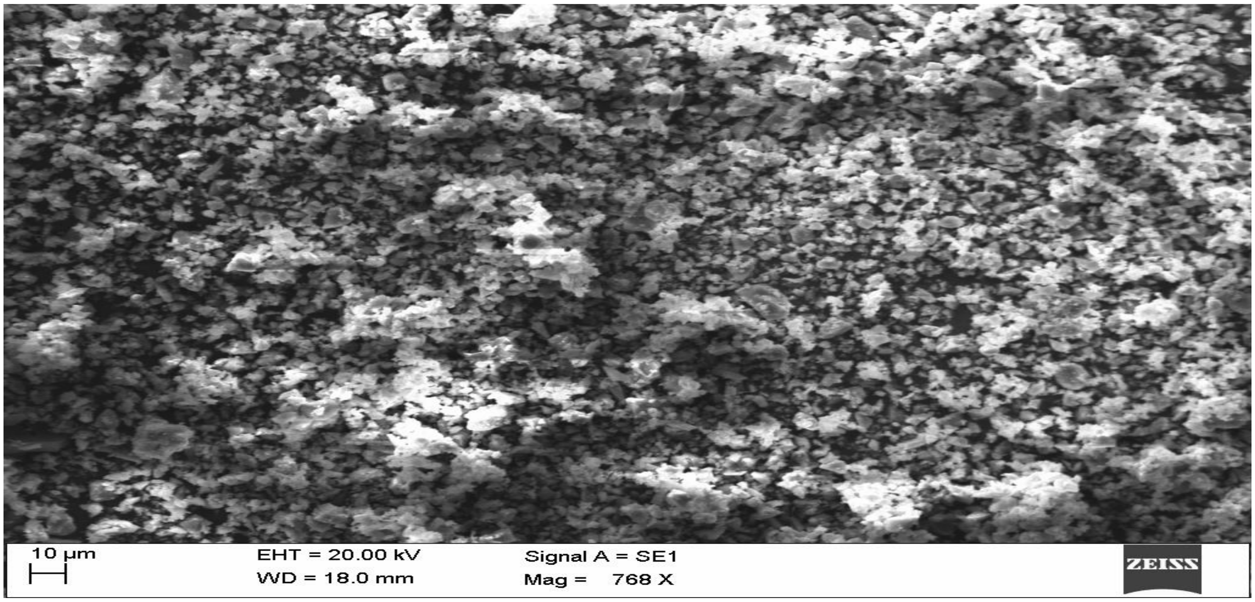


Fig 3.7 SEM image of Alccofine 1203 used for the purpose of the test at 768X.

3.2.3.2 <u>EDS analysis of Alccofine</u>:-

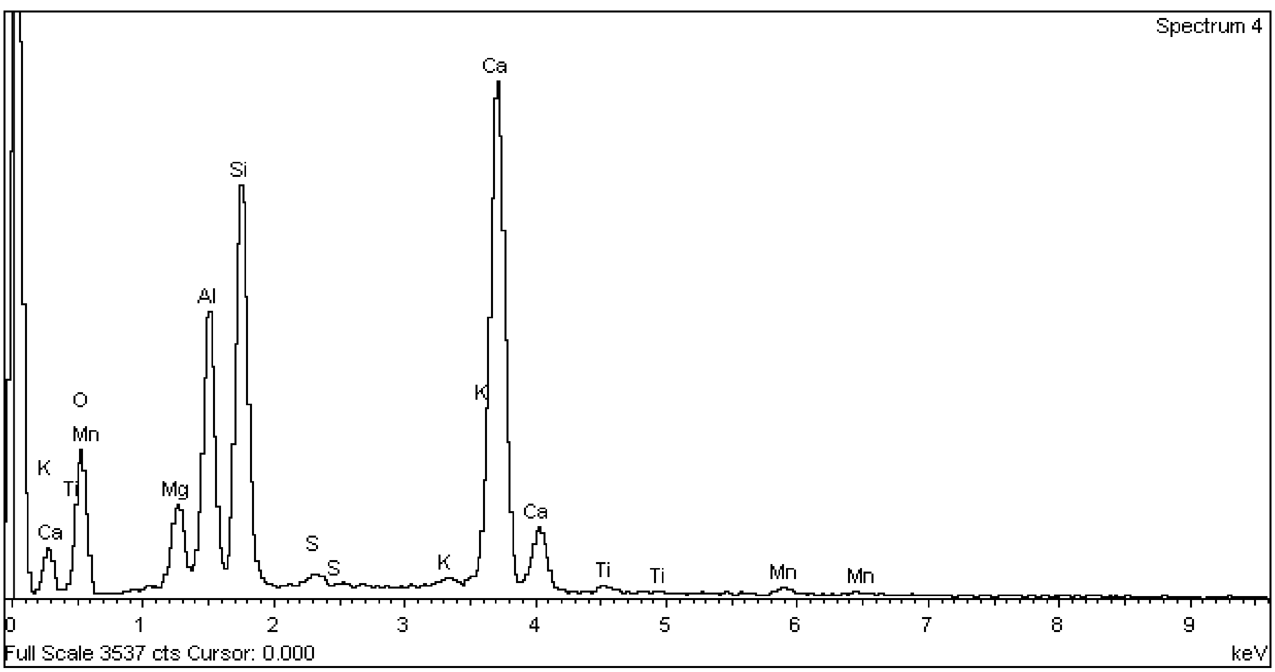


Fig 3.8 EDS Spectrum of Alccofine.

Table 3.3: EDS results of alccofine 1203.

Element	Weight%
O K	40.69
Mg K	3.45
Al K	9.77
Si K	15.83
K K	0.54
Ca K	0.40
Ti K	27.89
Fe K	0.50
Total	0.94

3.2.4 Silica fume:-

Silica fume is a byproduct of silicon metal or ferrosilicon alloys when high purity quartz with coal is reduced in electrical arc furnace about 2000°C .The smoke emits from the furnace operation is collected in cloth bags . Because of its chemical and physical properties, it is a very reactive pozzolan. The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307. Following are the several properties of Silicafume used for the experiment:-

- Fineness: - 15000-35000 m^2/kg.
- Sp.Gravity-:-2.17-2.2.
- Bulk density:- 130-430kg/m^3

Fig 3.9 Silica fume used for the experiment.

3.2.4.1 Microstructure analysis of Silicafume through SEM:-

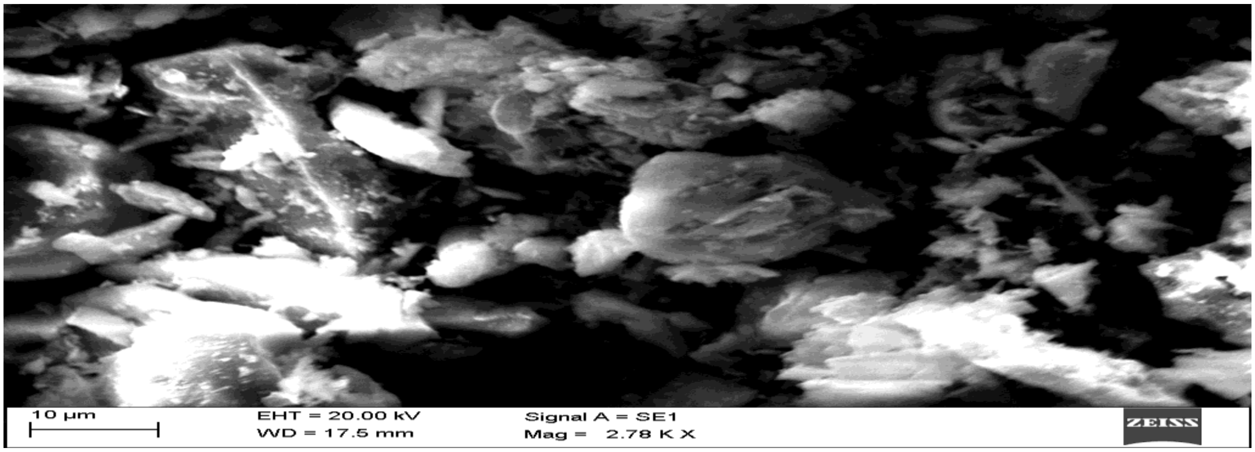


Fig 3.10 SEM image of Silicafume used for the purpose of the test at 2780X.

3.2.3.2 EDS analysis of Silicafume:-

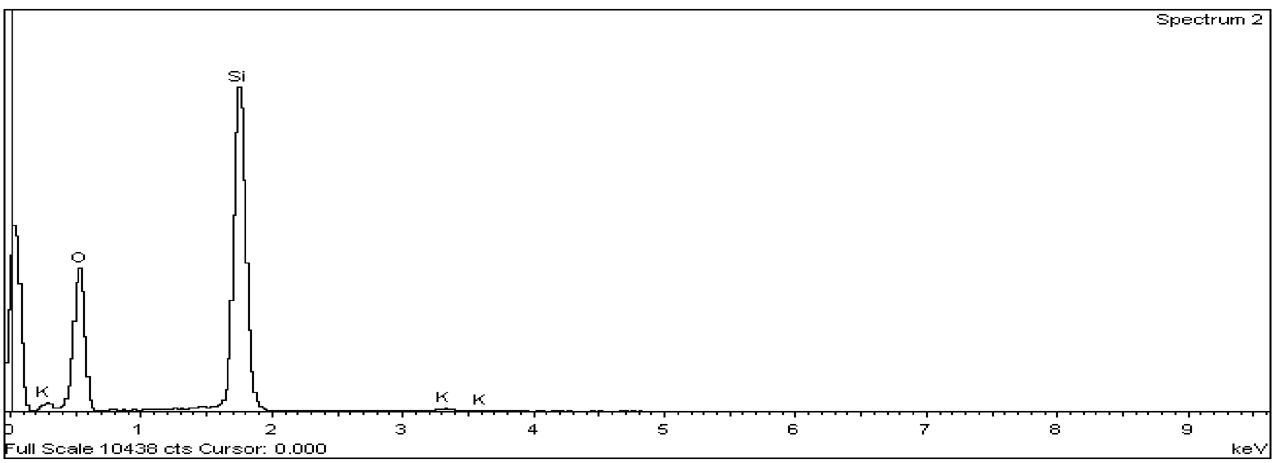


Fig 3.11 EDS Spectrum of Silicafume

Table 3.4: EDS results of Silicafume.

Element	Weight%
O K	60.43
Mg K	0
Al K	0
Si K	39.13
K K	0.44
Ca K	0
Ti K	0
Fe K	0
Total	100

3.2.5 Fine aggregate:-

Aggregate most of which passes 4.75-mm IS Sieve and contains only so much coarser material as permitted in table 4 of IS 383:2016 is termed as Fine Aggregate (FA). According to clause 5.3 of IS 456:2000, aggregates shall be suitable with regard to strength, durability of concrete and freedom from harmful effects. It should not contain more than 0.5 % of sulphates and should not absorb more than 10 % water of their own mass. River sand (yellow) conforming to Zone-II has been used in the experiment work.

Fig 3.12 River sand.

3.2.6 Water:-

Water is a vital ingredient of casting as well as curing of mortar, which actively participate in hydration reaction and formation of C-S-H gel as well. In present work of thesis we have used tap water for the purpose of casting.

3.2.7 Chemical admixture:-

Super plasticizing admixture of a particular brand (conforming to IS 9103:1999) has been used in concrete mixes to make fresh concrete workable. As the mixes are very stiff 0.8% super plasticizing admixture by weight of cementitious material has been used. But this was not enough to make slump more than 50mm. As the focus was on strength criteria of concrete percentage of admixture was not varied mix to mix but remains 0.8% for all the mixes. This admixture has been added into the mix after adding normal water of 50 to 70% to the mix

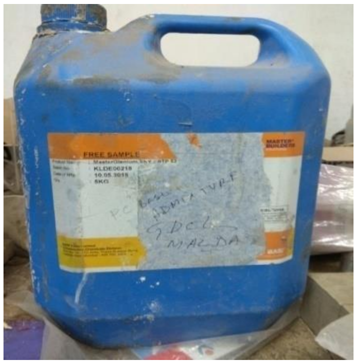


Fig 3.13 Chemical admixture

3.3 Test Specimen:-

The specimen prepared with varying percentages of flyash as partial replacement of ordinary Portland cement, and Silicafume, alccofine as additives with their nomenclature are tabulated below:-

Fig 3.14: Specimen preparation for compressive strength test.

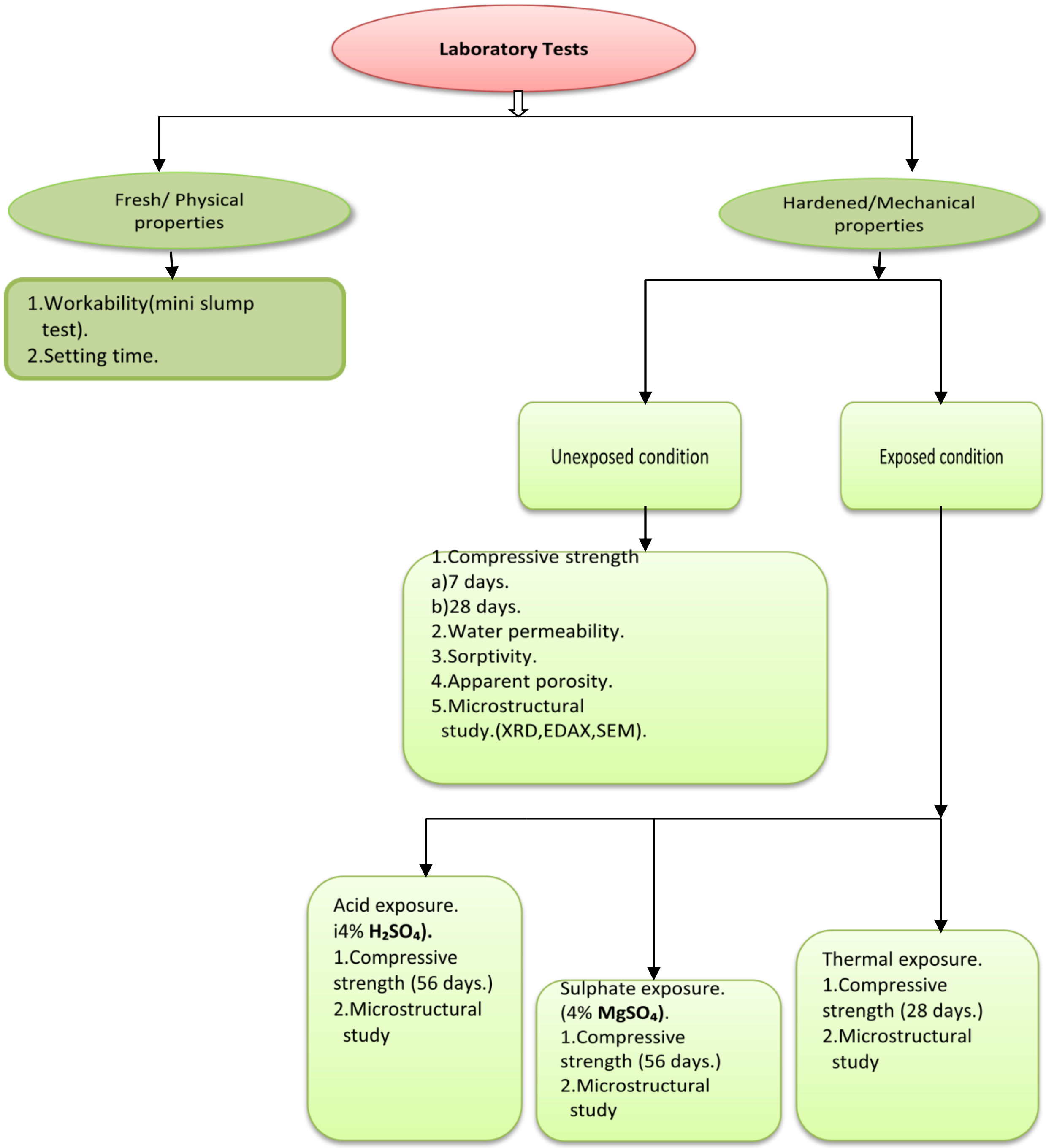
Table 3.5: Details of mortar mixes using different % of OPC replaced with Flyash and Alccofine respectively.

Mixer no	Notations	Compositions	W/cm	No of Sample
1	C100	100%OPC	0.36	21
2	C70FA30AF5	70%OPC+30%FA+5%AF	0.36	21
3	C70FA30AF10	70%OPC+30%FA+10%AF	0.36	21
4	C70FA30AF15	70%OPC+30%FA+15%AF	0.36	21
5	C50FA50AF5	50%OPC+50%FA+5%AF	0.36	21
6	C50FA50AF10	50%OPC+50%FA+10%AF	0.36	21
7	C50FA50AF15	50%OPC+50%FA+15%AF	0.36	21

Table3.6: Details of mortar mixes using different % of OPC replaced with Flyash and Silicafume respectively.

Mixer no	Notations	Compositions	W/cm	No of Sample
1	C100	100%OPC	0.36	21
2	C70FA30SF5	70%OPC+30%FA+5%SF	0.36	21
3	C70FA30SF10	70%OPC+30%FA+10%SF	0.36	21
4	C70FA30SF15	70%OPC+30%FA+15%SF	0.36	21
5	C50FA50SF5	50%OPC+50%FA+5%SF	0.36	21
6	C50FA50SF10	50%OPC+50%FA+10%SF	0.36	21
7	C50FA50SF15	50%OPC+50%FA+15%SF	0.36	21

- **Flow chart of experimental programme**



3.4 Test Method:-

3.4.1 Specific gravity test of cement:

Specific gravity of cement was determined by Specific gravity bottle.

Weight of the empty bottle with stopper was taken as W1 (say).The bottle was filled with water and weight of bottle with water = W2.Then the bottle was dried and filled with kerosene. This weight was W3. Again bottle was dried and cement was poured about half of bottle. This weight was taken as W4.Kerosene was added to cement in bottle till it flash with graduated mark. Weight was taken as W5.

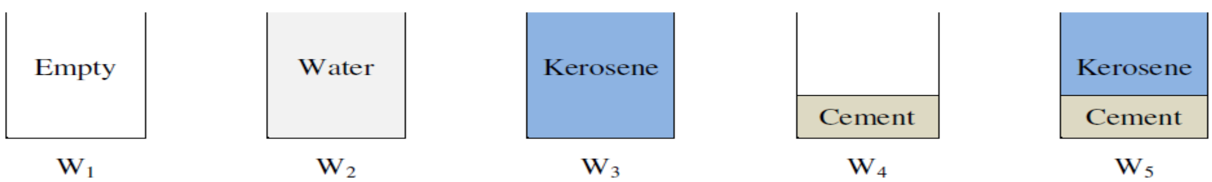
Weight of the empty bottle= W_1

Weight of bottle + Water= W_2

Weight of bottle + kerosene=W_3

Weight of bottle+ Cement= W_4

Weight of bottle+ Cement + kerosene = W_5



$$\text{Specific gravity of cement} = \frac{\text{Weight of cement}}{\text{Weight of equivalent vol. of water}}$$

$$= \frac{\text{Weight of cement}}{\text{Wt. of equivalent vol. of kerosene}} \times \frac{\text{Wt. of that vol. of kerosene}}{\text{Weight of equivalent vol. of water}}$$

$$= \frac{\text{Weight of cement}}{\text{Wt. of equivalent vol. of kerosene}} \times \text{Sp. gr. of kerosene}$$

$$= \frac{W_4 - W_1}{(W_3 - W_1) - (W_5 - W_4)} \times \frac{W_3 - W_1}{W_2 - W_1}$$

3.4.2 Standard Consistency of cement:-

The standard consistency of a cement paste is defined as that consistency which will permit the vicat plunger to penetrate to a point 5 to 7mm from the bottom of the vicat mould, test method conforming to IS: 4031 (Part 4) 1988.

APPARATUS

- Vicat Apparatus Conforming to IS: 5513-1976.
- Balance of capacity 1Kg and sensitivity to 1gram.
- Gauging trowel conforming to IS: 10086-1982.

PROCEDURE

- Unless otherwise specified this test shall be conducted at a temperature 27 + 20°C and the relative humidity of laboratory should be 65 ± 5%.
- Prepare a paste of weighed quantity of cement (300gms) with weighed quantity of potable or distilled water, taking care that the time of gauging is less than neither 3minutes nor more than 5minutes and the gauging is completed before any sign of setting occurs.
- The gauging is counted from the time of adding water to the dry cement until commencing to fill the mould.
- Fill the vicat mould with this paste resting upon a non-porous plate.
- Smoothen the surface of the paste, making it level with the top of the mould.
- Slightly shake the mould to expel the air.
- In filling the mould operator's hands and the blade of the gauging trowel shall only be used.
- Immediately place the test block with the non-porous resting plate, under the rod bearing the plunger.
- Lower the plunger gently to touch the surface of the test block and quickly release, allowing it sink into the paste.
- Record the depth of penetration.

- Prepare trial pastes with varying percentages of water and test as described above until the plunger is 5mm to 7mm from the bottom of the vicat mould.

Fig 3.15 Vicat apparatus

CALCULATIONS

$$\text{Standard consistency (\%)} = \frac{\text{Weight of water added}}{\text{Weight of cement}} \times 100$$

3.4.3 Sorptivity test:-

The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems such as corrosion of reinforcing steel, and damage due to freeze-thaw cycling or wetting and drying cycles.[18] In the 1970's, Hall suggested the importance of studying the unsaturated flow of water in porous mediums. The capillary potential (suction), the water diffusivity (D), and the hydraulic conductivity (K) were stated as being the three key parameters that needed further investigation (Hall 1977). Following this, research was conducted to devise experimental methods to quantify and model transport properties. Sorptivity was introduced as a testing method that consisted of a unidirectional water absorption front within a specimen.

The cumulative absorbed volume of water per unit area of inflow surface (i) was related to the square root of the elapsed time ($t^{0.5}$). The following relationship was developed.

$$i = S\, t^{0.5}$$

Apparatus used:-

Pan, Support device, timing device, Paper towel or cloth, top pan balance, environmental chamber.

Procedure:-

ASTMC 1585 test method had been followed for the purpose of sampling and testing.

Fig 3.16 Sorptivity test setup

3.4.4 Compressive strength:-

To find the compressive strength of standard cement sand mortar cubes, following are the apparatus and procedures of the test.

Apparatus:-

7.06cm cubes moulds (50mm x50mm face areas), apparatus for gauging and mixing mortar, vibrator, compression testing machine etc.

Procedure for Compressive Strength of Mortar:-

I have taken cementitious materials and river sand in the mix ratio 1:2.628 by weight in a pan. The standard sand shall be of quartz, of light, gray or whitish variety and shall be free from silt. The sand grains shall be angular, the shape of grains approximating to the spherical form, elongated and flattened grains being present only in very small quantities.

Mix the cement and sand in dry condition with a trowel for 1minitues and then add water. The quantity of water shall be (p/4+3) % of combined weight of cement and sand where, p is the % of water required to produce a paste of standard consistency determined earlier. In our case standard consistency of OPC ultratech 43 is 33% and water cement ratio is 0.36 although the test.

Add water and mix it until the mixture is of uniform color. The time of mixing shall not be < 3 minutes & not > 4 minutes.

Immediately after mixing the mortar, place the mortar in the cube mould and prod with the help of the rod. The mortar shall be prodded 20 times in about 8 sec to ensure elimination of entrained air.

If vibrator is used, the period of vibration shall be 2 minutes at the specified speed of 12000±400 vibrations /minutes. Then place the cube moulds in temperature of 27±2^{o} C and 90% relative humidity for 24 hours.

After 24 hours remove the cubes from the mould and immediately submerge in clean water till testing. Take out the cubes from water just before testing. Testing should be done on their sides without any packing.

The rate of loading should be 350 kg/cm^2/minute and uniform. Test should be conducted for 3 cubes and report the average value as the test result for both 7day and 28 day compressive strength.

Fig 3.17. Compressive Strength testing setup

3.4.5 Sulphuric Acid:-

Durability of the sample has been investigated by the sample exposed to Sulphuric acid conforming to IS 266: 1993 for 56 days after 28 days normal water curing at room temperature. 4% diluted sulphuric acid solution has been used for the purpose of experiments. Sulphuric acid about 98% was mixed with potable water at a ratio of 41gm of concentrated (98%) H_2SO_4 to 1 liter of H_2O. Each of the containers contains about 4.5L of potable water and then 184 gm concentrated acid added. The acidity of prepared solution at day 1 was 1.05pH and before taking out of solution the pH was 1.12.

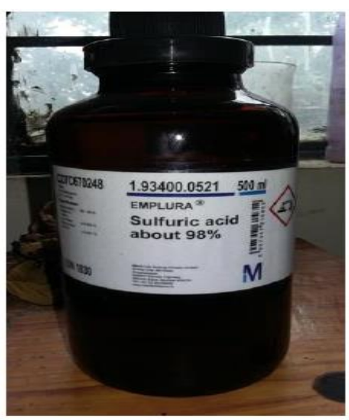


Fig 3.18: Sulphuric acid bottle.

3.4.6 Acidity test of sulphuric acid solution:-

Acidity of water and acid was determined by electronic pH meter. The testing Machine was switch on by pressing ON/OFF button. The electrode was immersed in the acid solution in at least 20 mm depth, and gently stirred. The pH reading was taken when the value displayed was stabilized. pH value of Sulphuric acid used for the purpose of this experiment is 1.7.

Fig 3.19. pH test of Sulphuric acid used for experiment.

3.4.7Microstructure of concrete specimen through SEM:

Scanning Electron Microscope (SEM) is a type of electron microscope that produces Topography images of a sample by scanning the surface with a focused beam of electrons. When a specimen is irradiated with a fine electron beam (called the electron probe), secondary the SEM, and image of concrete samples can be seen by magnifying 30,000 times. Electrons are emitted from the specimen surface. Topography of surface can be observed by two dimensional scanning of the electron probe and acquisition of an image from the detected secondary electron.

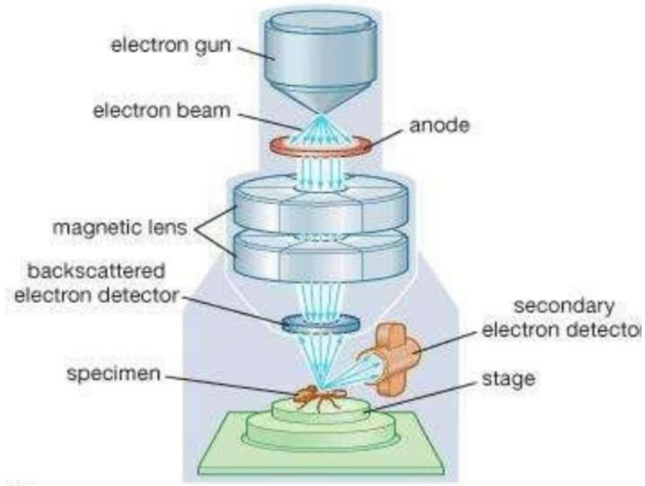


Fig. 3.20 Schematic diagram of working principle of SEM

Fig 3.21 Scanning Electron Microscope instrument and prepared sample

Ordinary Portland cement is the key ingredients in production of concrete. The formation of hydration product occurs in blended concrete produced with ordinary Portland cement and mineral admixtures like flyash, Silicafume and alccofine in this study , while comes in contact with water. Its very much possible to study the formation of hydration product mainly hydrated silicate of calcium i.e C-S-H phase, accompanied with calcium hydroxide also called portlandite and hydration products of calcium aluminates i.e. ettringite by SEM Scanning electron microscopy) and their compositions by EDS (Energy dispersive X-ray spectroscopy). By studying the internal morphological changes of the concrete due to hydration reaction it allows us to track the hydration process mainly changes in C-S-H phase. In initial stages of hydration may encompass the C-S-H matrix with needles or by radial concentration. Later on with further progress of reaction it appears to be fibers lattice, sometimes 3-D plate's so-called honeycomb.

The prime components of the cement paste during hardening of the mass is the phase denoted by C-S-H often called phase of tobermorite due to similarities found with natural mineral tobermorite, because its chemical compositions is quite similar i.e $5Cao6Sio_2.5H_2O$. Although the hydration is hardening of cement paste is formed on density of C-S-H gel combined with the addition of water and crystallization of ettringite and calcium hydroxide intergrowths forming and filling pores in hardening cement paste.

At the beginning of the hydration reaction, due to hydrolysis of tricalcium silicate (C_3S) and dicalcium silicates (C_2S), what has a place after few hours of mixing of Portland cement, that results calcium hydroxide at solid phase of paste in present primarily in the form of portlandite, which is in the form of massive hexagonal structure almost about 40 microns size, aggregating takes the shape of column, which is about 25% by volume of solid phase.

In second phase of hydration reaction of cement paste, first form of C-S-H are created, which is 50-60% of the volume of all solid phase. As elaborated by [20]Diamond, model of the morphological distribution of C-S-H gel in cement paste is distinguished from filter form of size 2 micron, which resulting from early stages of hydration, which appears to be in mesh also looks like "Honeycomb" structure form after prolonged hydration reaction .

In the third and final stages of hydration reaction, it appears to be filling of pores of hardening cement paste by short fibers or laminar phase of calcium silicates, tenure of which may be from several days to several months and covers almost complete hydration of the cement. A distinguished feature of this phase is transformation of calcium aluminate trisulphate ($3Cao.Al_2O_3.3CaSo_4.32H_2O$) to Calcium aluminate monosulphate ($3Cao.Al_2O_3.CaSO_4.12H_2O$). Ettringite crystals appear to be in the form of elongated needles while tobermorite creates lamellar aggregates.

Energy-Dispersive X-ray spectroscopy (EDS):

A Scanning Electron Microscope may be equipped with an EDS analysis system to enable it to perform compositional analysis on specimens. EDS analysis is useful in identifying materials and contaminants, as well as estimating their relative Concentrations on the surface of the specimen.

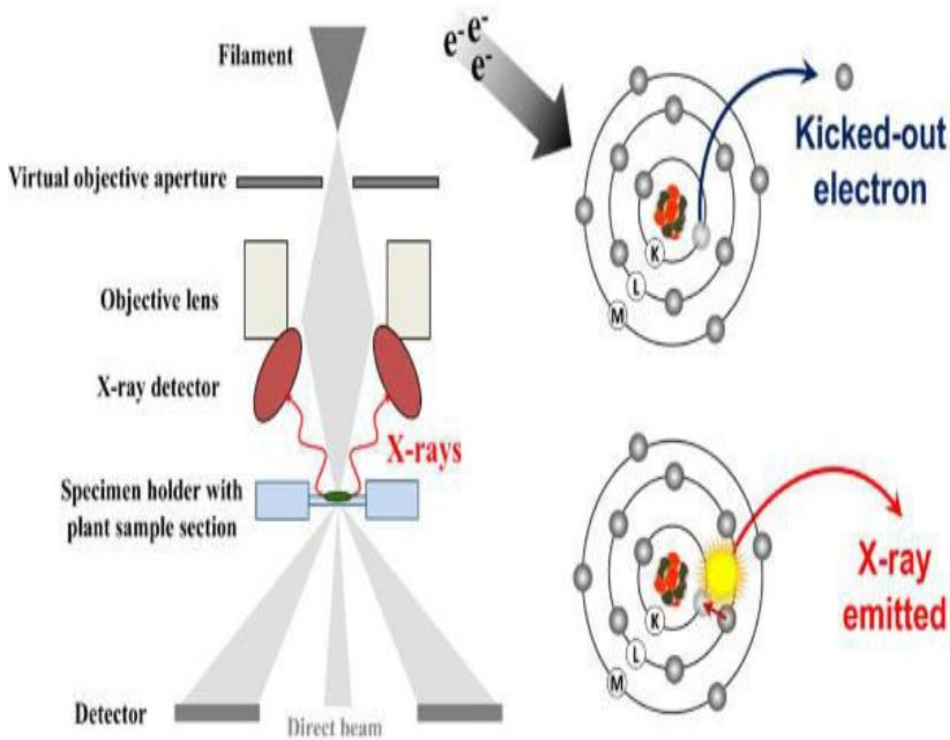


Fig 3.22 Schematic diagram of EDS spectroscopy principle

4.1 General:-

Vision of the study was to observe the improvement if any by replacing the cement with various mineral admixtures i.e. silica fume and alccofine and Fly ash as additives and partial replacement to the ordinary Portland cement. In this chapter we will be discussing about the various test like 7 days and 28 days compressive strength results in unexposed condition, sample exposed to elevated temperature as high as 800°C and their compressive strength and change in weight in thermal exposure, also sample exposed to sulphuric acid and $MgSO_4$ solution for 56th days and their compressive strength and change in weight in exposed condition had been studied. The micro structural changes of the sample performing better under various exposed condition also had been studied and interpretations of the results obtained presented graphically and discussed.

4.2Workability:-

[11] Workability of concrete refers to its fresh property which defines its ease to mixed, placed, consolidated and finished. We have measured the workability of the mortar specimen following the guidance mentioned under **ASTM C230 / C230M-14**, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement. The results of the various mixes are mentioned below:-

Fig 4.1 Flow table test setup

Table 4.1		
Flow Table Results.		
W/C-0.36		
SL NO	**Mix type**	**Flow Table(mm)**
1	**C100**	130
2	**C70FA30AF5**	125
3	**C70FA30AF10**	121
4	**C70FA30AF15**	130
5	**C50FA50AF5**	100
6	**C50FA50AF10**	108
7	**C50FA50AF15**	120
8	**C70FA30SF5**	112
9	**C70FA30SF10**	102
10	**C70FA30SF15**	100
11	**C50FA50SF5**	110
12	**C50FA50SF10**	100
13	**C50FA50SF15**	100

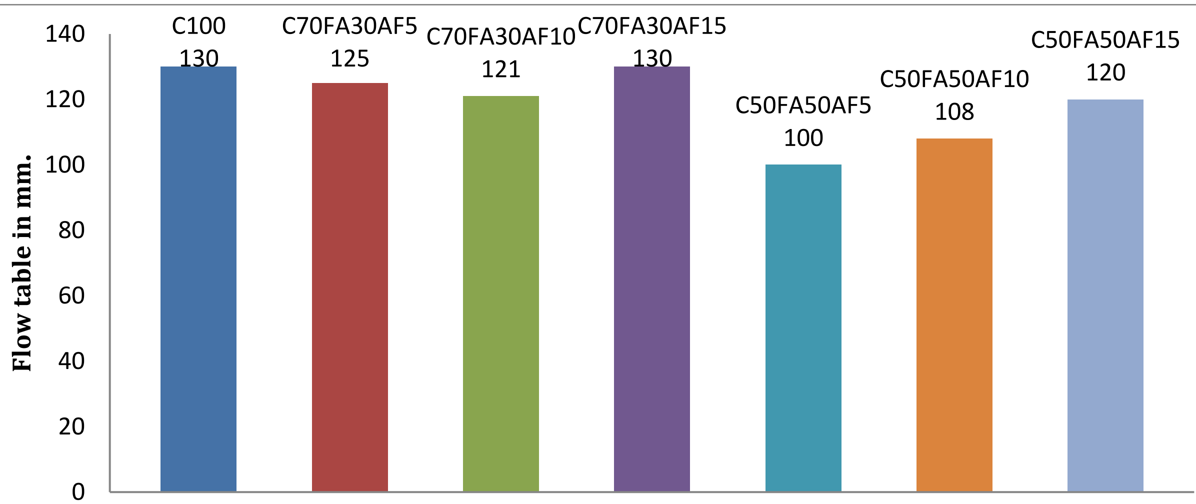


Fig 4.2 Comparision of workability interms of flow table for mix contains various % of Flyash and Alccofine with the control mix.

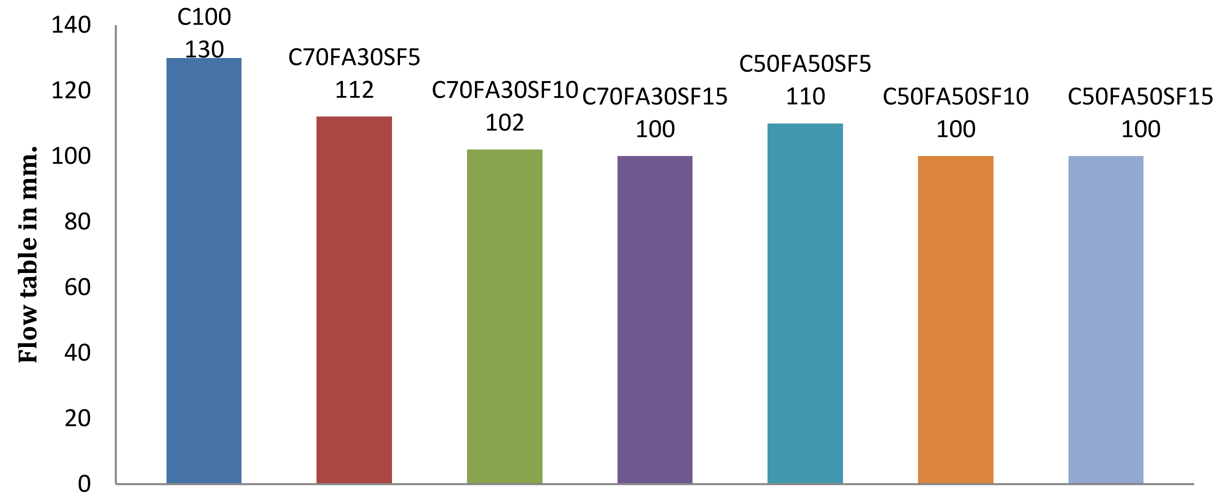


Fig 4.3 Comparision of workability interms of flow table for mix contains various % of Flyash and Silicafume with the control mix.

Discussions:-

From the results obtained from various mix, we have observed that workability of the specimen reduces for the sample with Fly ash replacement of 30%, with the value being the closest for the alcofine percentage of 15% [6, 18] which points to the fact that alccofine increases water demand. Similar trend was observed for the mix containing Silicafume as it was seen that increasing the amount of silica fume did not cause an increase in workability of the mortar.

4.3Water absorption:-

The test for water absorption has been conducted by the method mentioned in the **ASTM C 140,** and results of the various blended sample are mentioned below.

Table 4.2		
Water absorption Results.		
W/C-0.36		
SL NO	**Mix type**	**Water absorption (%)**
1	**C100**	8.28
2	**C70FA30AF5**	4.59
3	**C70FA30AF10**	3.408
4	**C70FA30AF15**	2.91
5	**C50FA50AF5**	4.48
6	**C50FA50AF10**	8.69
7	**C50FA50AF15**	3.92
8	**C70FA30SF5**	5.03
9	**C70FA30SF10**	3.23
10	**C70FA30SF15**	5.6
11	**C50FA50SF5**	5.67
12	**C50FA50SF10**	4.59
13	**C50FA50SF15**	3.92

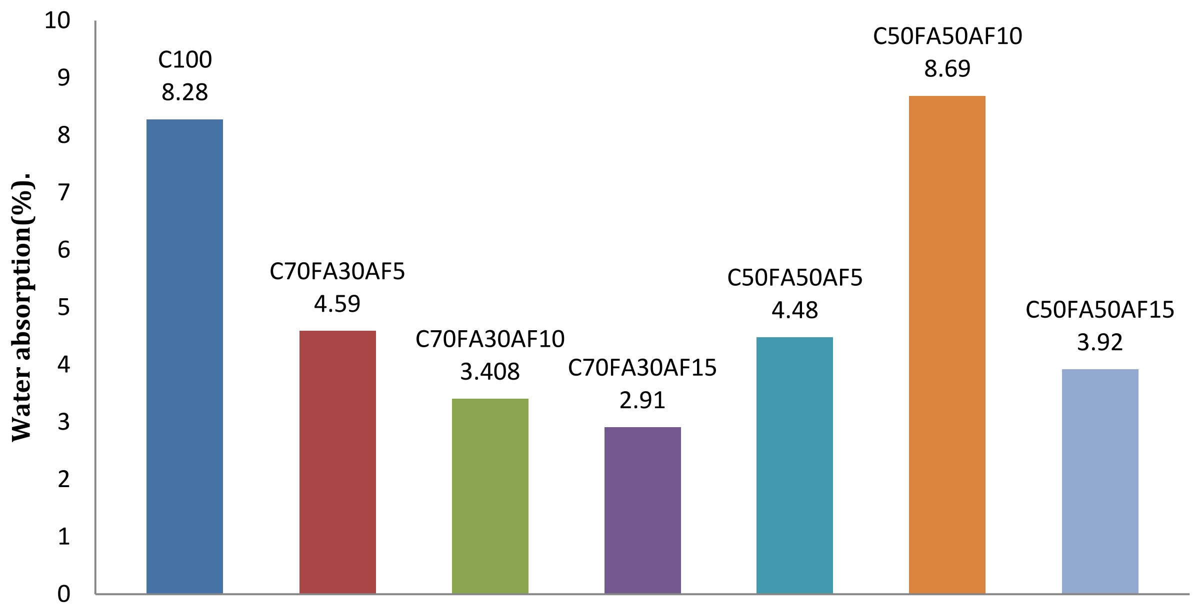


Fig 4.4 Comparision of water absorption in % for mix contains various % of Flyash and Alccofine with the control mix.

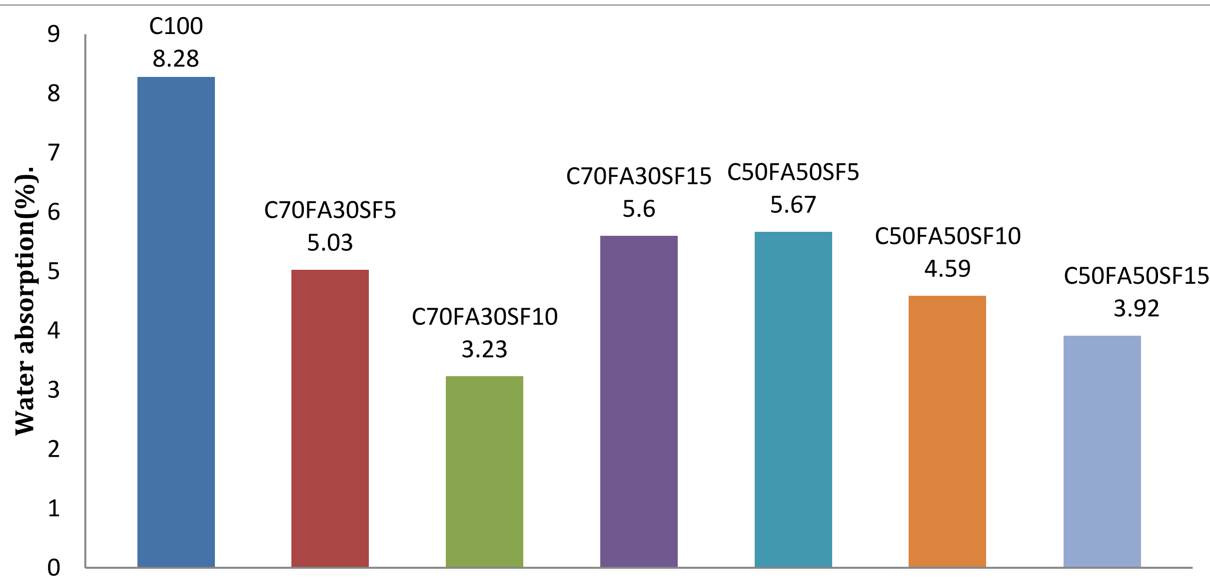


Fig 4.5 Comparision of water absorption in % for mix contains various % of Flyash and Silicafume with the control mix.

Discussions:-

It has been observed from the results that for the ternary mix composed of 30% Flyash, absorption of water is decreasing substantially with percentage increase in alccofine, which may further attribute to the reduction of the pore structure and improvement of C-S-H gel matrix of the mix, [8] where pore structure of concrete mix mainly related to the volume and size of the inter connected capillary pores. The pore network basically provides space for the movement of fluid into the mortar. For the mix prepared with flyash and Silicafume it has been observed that mix prepared with 30% flyash and 10% Silicafume performed better, which reduces water absorption by 60.99% lesser than the control mix. On the other hand mix comprises with alccofine and flyash there is a decreasing trend of water absorption with percentage increase in alccofine for 30% flyash , where the best performing sample is C70FA30AF15 which water absorption is 64.855% lesser than control mix.

4.4Bulk density:-

The bulk density reflects the volume taken up by the cement plus any air trapped between the particles, is the mass of the material related to a specific volume and for cement is normally expressed as "kilograms per cubic meter". Here are the results of bulk density of the mix as tabulated below.

Table 4.3		
Bulk density Results.		
W/C-0.36		
SL NO	**Mix type**	**Bulk density (Kg/m³)x 10³**
1	**C100**	2.051
2	**C70FA30AF5**	2.046
3	**C70FA30AF10**	2.044
4	**C70FA30AF15**	2.077
5	**C50FA50AF5**	2.043
6	**C50FA50AF10**	1.894
7	**C50FA50AF15**	2.028
8	**C70FA30SF5**	1.947
9	**C70FA30SF10**	2.078
10	**C70FA30SF15**	1.989
11	**C50FA50SF5**	2.063
12	**C50FA50SF10**	1.93
13	**C50FA50SF15**	1.945

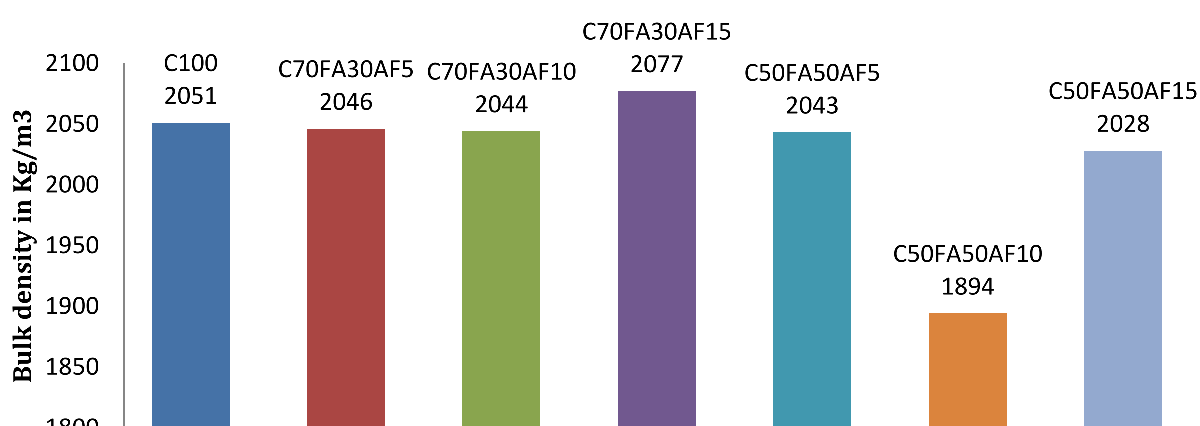


Fig 4.6 Comparision of Bulk density in Kg/m³ for mix contains various % of Alccofine and Flyash with the control mix.

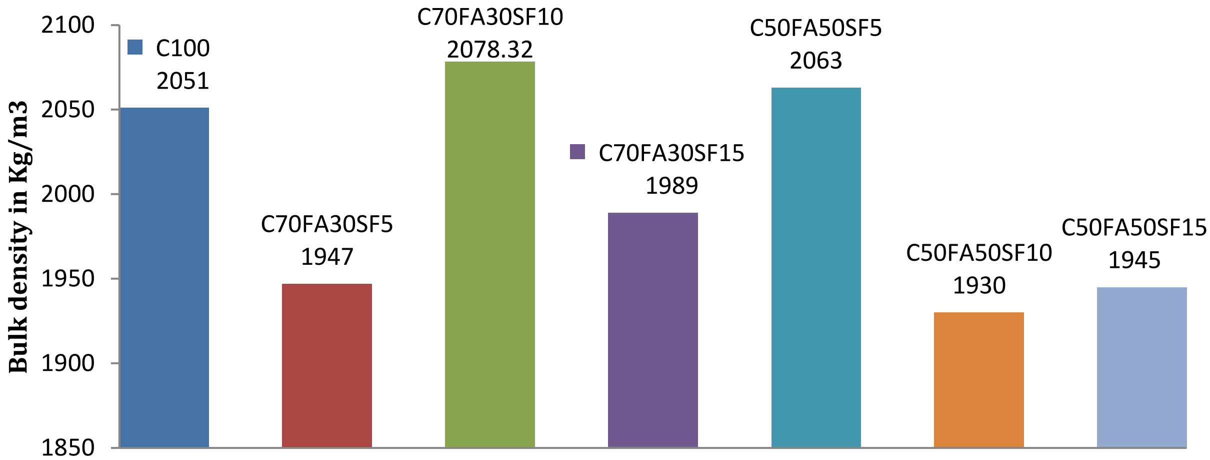


Fig 4.7 Comparision of Bulk density in Kg/m^3 for mix contains various % of Silicafume and Flyash with the control mix.

Discussions:-

From the results obtained from test of bulk density, for the mix consisting of alccofine and 30% flyash it was seen that with the increase in percentage of alccofine there is a sharp increase in bulk density for the alccofine range from 5% to 15% with maximum density achieved for the mix C70FA30AF15 which is 1.25% higher than the control mix, this may be due to [21] ultrafine particle size and surface area of alccofine which leads to dense formation of hydration gel causing reduction in pore network, and increase density of the specimen. For the specimen consisting of silicafume and flyash there is not much increase in bulk density except for the mix C70FA30SF10 and C50FA50SF5.

4.5 Apparent Porosity:-

The apparent porosity is the percentage of total volume of the material which is occupied by interconnected pores. The true porosity is the porosity which includes the volume of both interconnected pores and closed pores.

Table 4.4		
Apparent porosity Results.		
W/C-0.36		
SL NO	**Mix type**	**Apparent porosity (%)**
1	**C100**	16.96
2	**C70FA30AF5**	12.67
3	**C70FA30AF10**	6.96
4	**C70FA30AF15**	11.57
5	**C50FA50AF5**	9.16
6	**C50FA50AF10**	9.28
7	**C50FA50AF15**	13.17
8	**C70FA30SF5**	12.67
9	**C70FA30SF10**	6.95
10	**C70FA30SF15**	11.57
11	**C50FA50SF5**	11.73
12	**C50FA50SF10**	9.28
13	**C50FA50SF15**	13.17

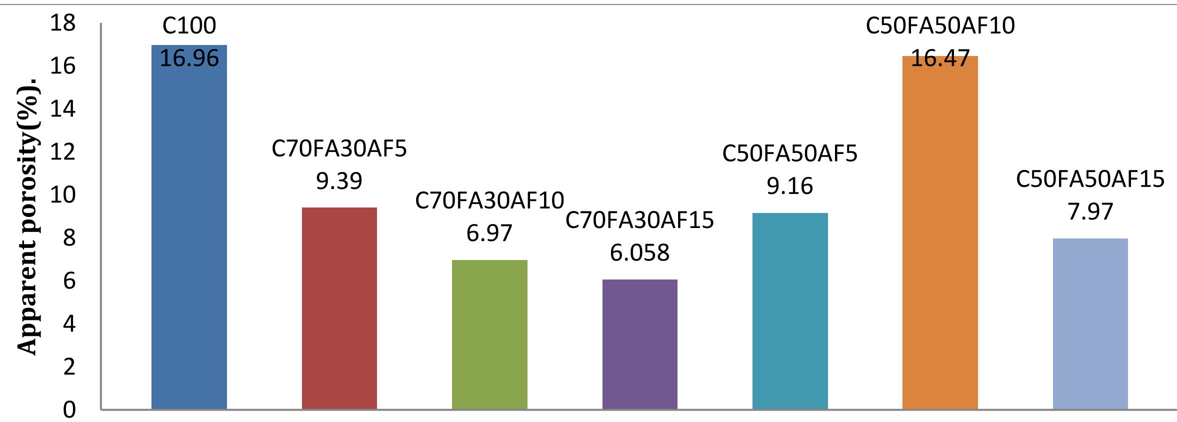


Fig 4.8 Comparision of apparent porosity in % for mix contains various % of Flyash and Alccofine with the control mix.

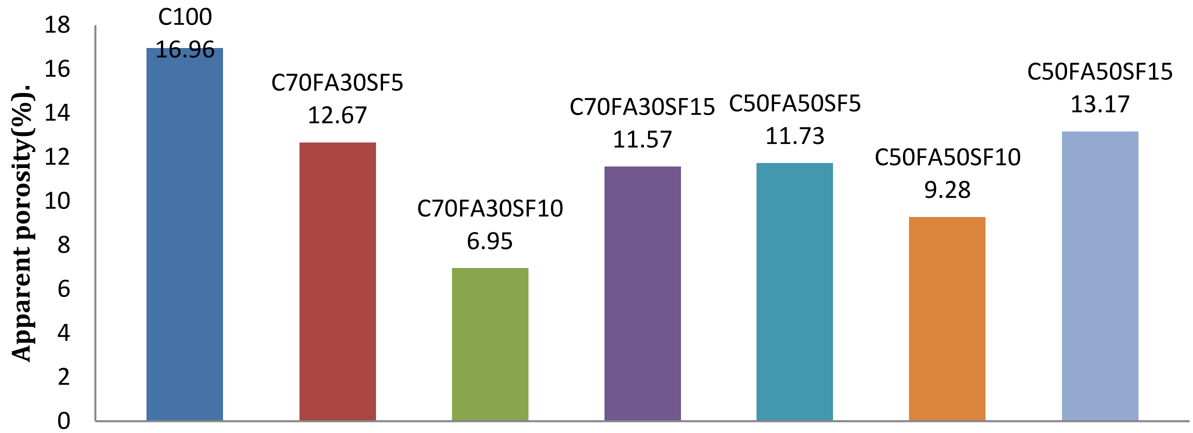


Fig 4.9 Comparision of apparent porosity in % for mix contains various % of Flyash and Silicafume with the control mix.

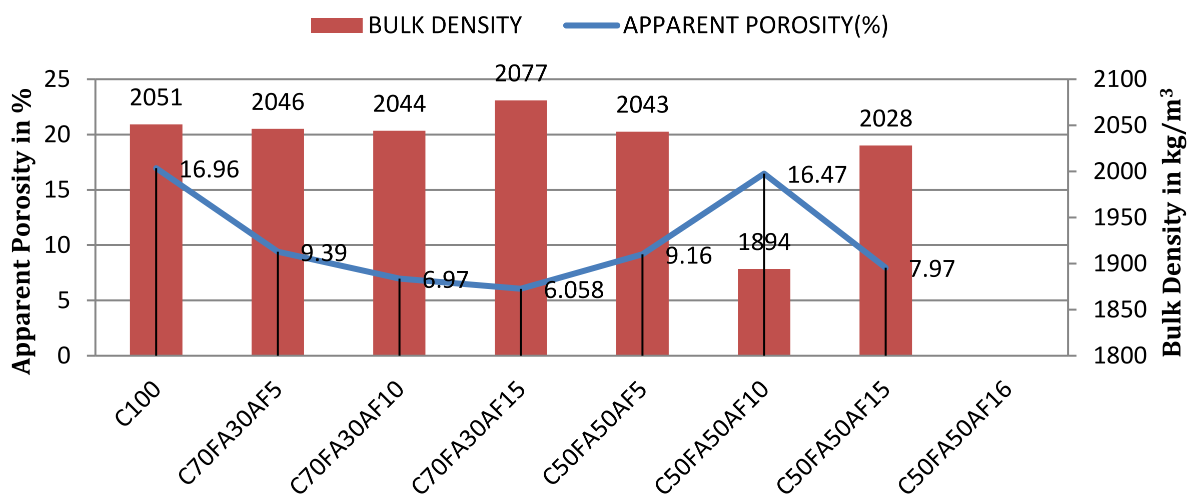


Fig 4.10 Comparision of Bulk density and Apparent porosity for the mix with varying percentage of Alccofine and flyash.

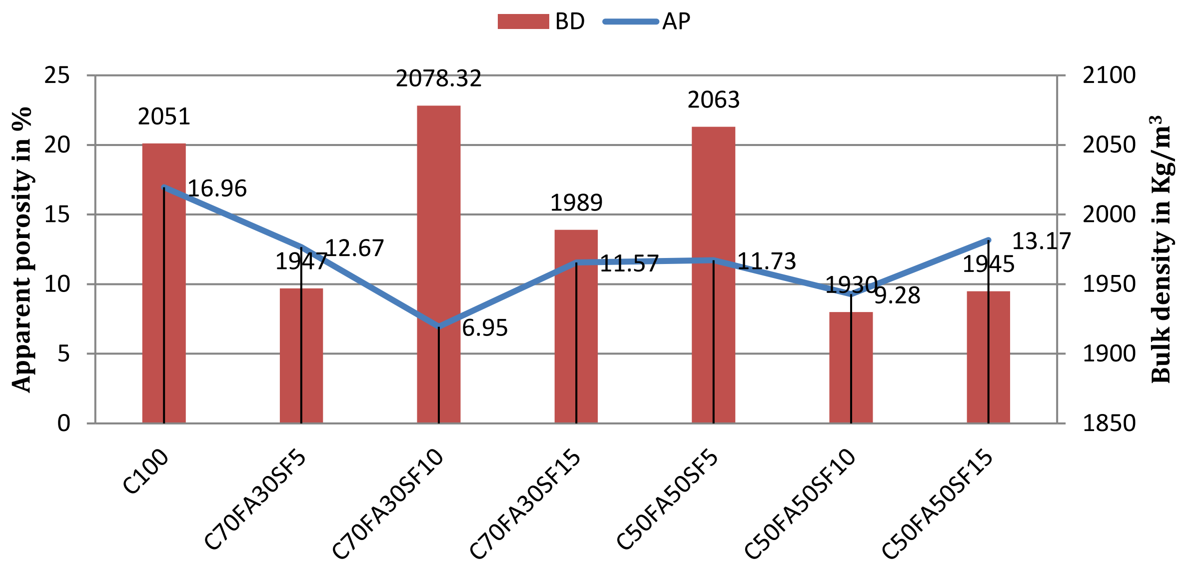


Fig 4.11 Comparision of Bulk density and Apparent porosity for the mix with varying percentage of Silicafume and flyash.

Discussions:-

Increase in bulk density decreases the apparent porosity of the concrete which is evident from the results obtained for both the mixes, where we can observe that mix containing alccofine has the highest bulk density value [16] the lowest apparent porosity, which signifies that increase in bulk density causes reduction in apparent porosity of the mix. Similarly mix series having Silicafume shows the highest bulk density value and the lowest apparent porosity which is almost 59.02% less than the control mix. Another aspect to notice is that the entire sample prepared with the addition of mineral admixtures as additives and partial replacement shows improvement in their properties in terms of apparent porosity, which may be due to their high reactive nature and pozzolanic property [6, 17] which causes the reduction in inside volume of the pore space inside the sample.

4.6 Sorptivity:-

Sorptivity [9] is the measure of the rate of capillary rise absorption by a concrete prism it is basically surface absorption of fluid of the concrete prism without any head of water.

ASTMC 1585 test method have been followed, in the following sections we will be discussing about the results of the sorptivity.

Table 4.5			
Sorptivity Results.			
W/C-0.36			
SL NO	**Mix type**	**Initial sorptivity coefficient (mm/see$^{0.5}$)x10^{-4}**	**Secondary sorptivity coefficient (mm/see$^{0.5}$) x10^{-4}**
1	C100	17	10
2	C70FA30AF5	26	3.3
3	C70FA30AF10	13	6.7
4	C70FA30AF15	40	6.7
5	C50FA50AF5	40	10
6	C50FA50AF10	17	6.7
7	C50FA50AF15	30	10
8	C70FA30SF5	40	20
9	C70FA30SF10	30	3.5
10	C70FA30SF15	60	10
11	C50FA50SF5	43	6.7
12	C50FA50SF10	37	10
13	C50FA50SF15	57	23

Here is the plot of absorption I (mm) vs. square root of time ($Sec^{0.5}$.) plot for the control mix and mix prepared with varying percentage of flyash, alccofine and Silicafume.

Fig 4.12:-SORPTIVITY TEST (CONTROL MIX) FOR 1ST SAMPLE C100

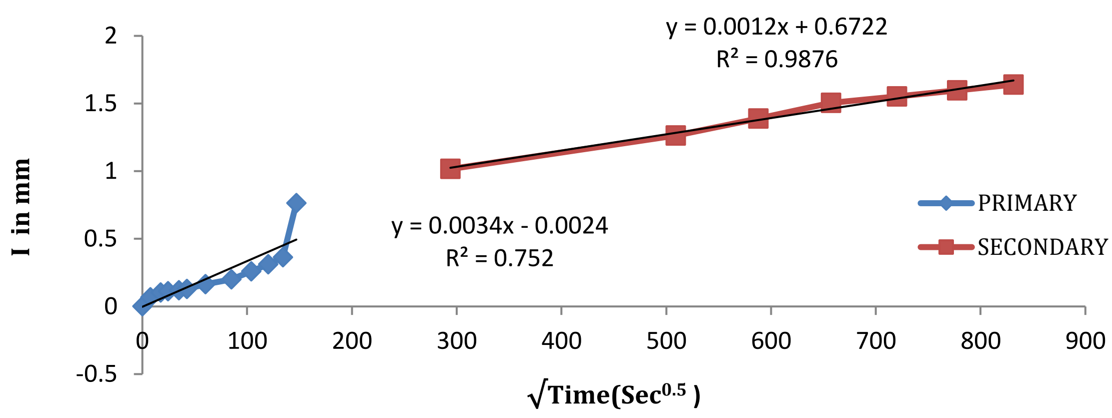


Fig 4.13:-SORPTIVITY TEST (CONTROL MIX) FOR 2ND SAMPLE C100

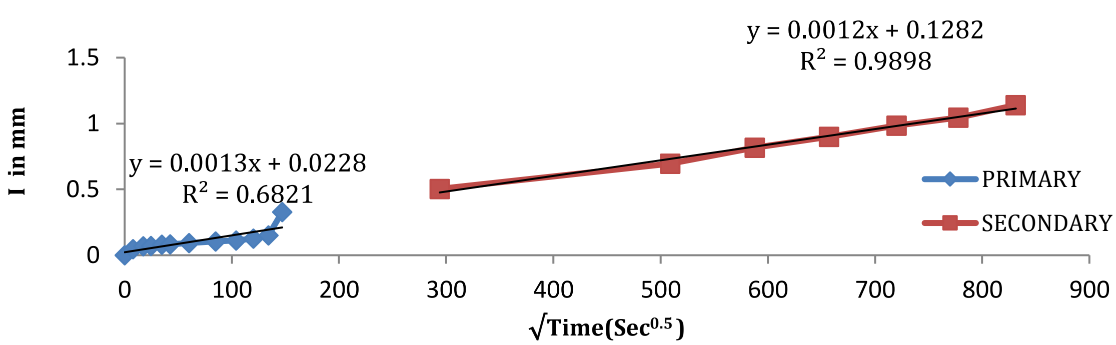
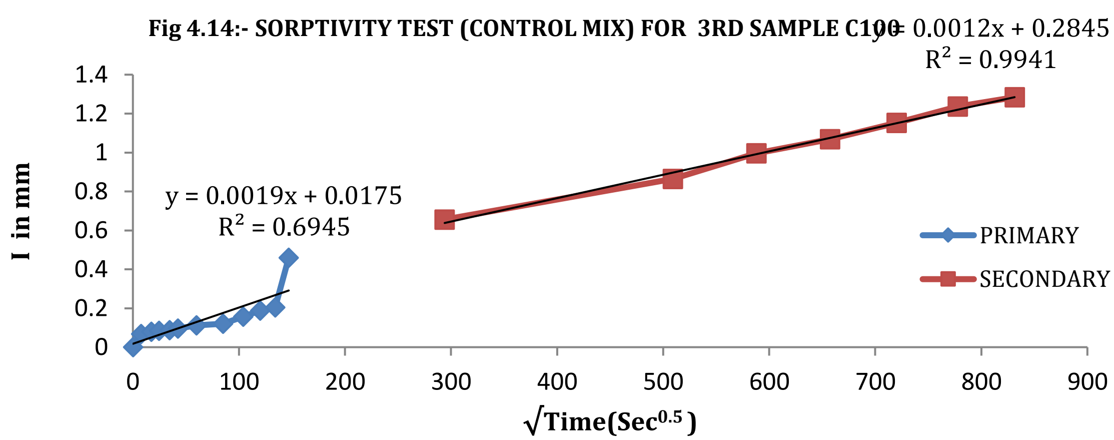


Fig 4.14:- SORPTIVITY TEST (CONTROL MIX) FOR 3RD SAMPLE C100



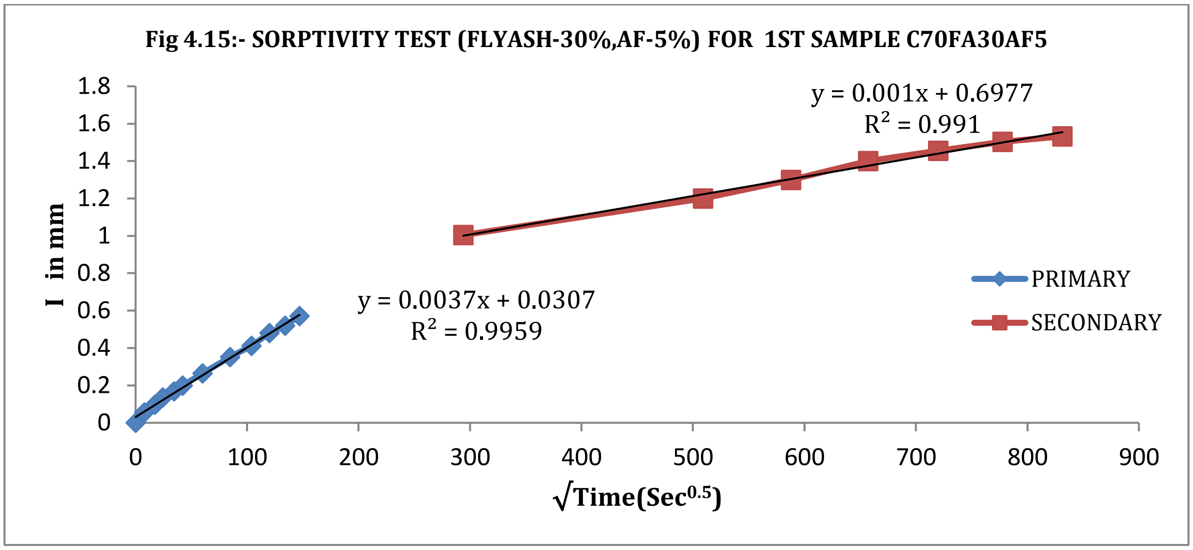


Fig 4.15:- SORPTIVITY TEST (FLYASH-30%,AF-5%) FOR 1ST SAMPLE C70FA30AF5
y = 0.001x + 0.6977
R² = 0.991
y = 0.0037x + 0.0307
R² = 0.9959
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)

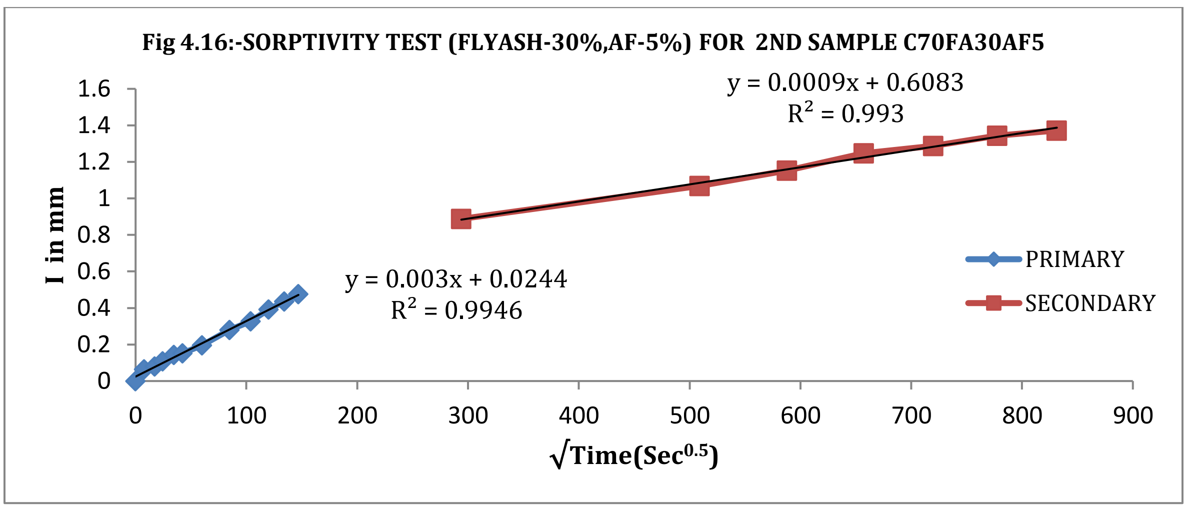


Fig 4.16:-SORPTIVITY TEST (FLYASH-30%,AF-5%) FOR 2ND SAMPLE C70FA30AF5
y = 0.0009x + 0.6083
R² = 0.993
y = 0.003x + 0.0244
R² = 0.9946
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)

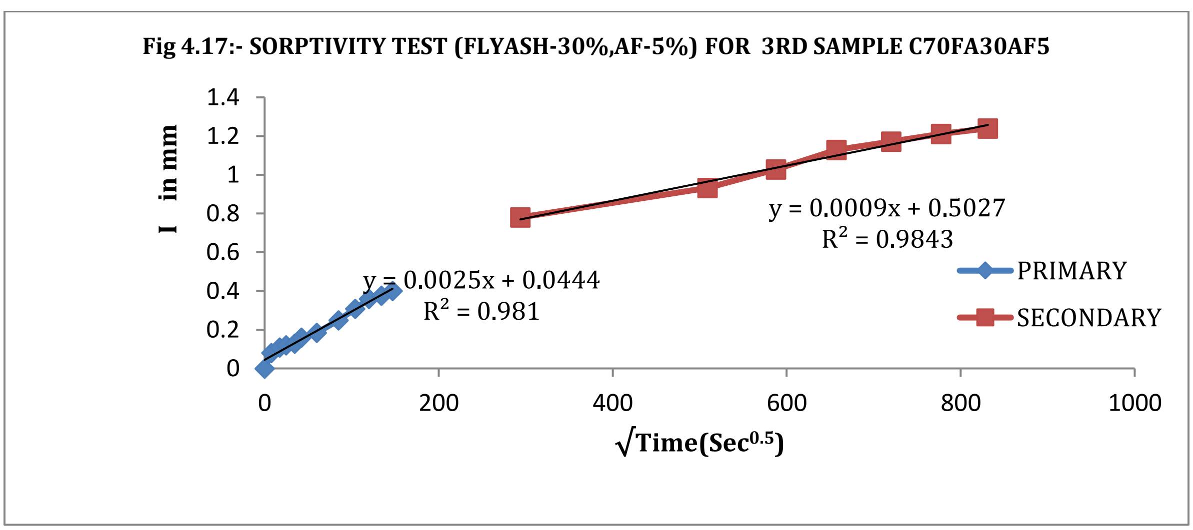


Fig 4.17:- SORPTIVITY TEST (FLYASH-30%,AF-5%) FOR 3RD SAMPLE C70FA30AF5
y = 0.0009x + 0.5027
R² = 0.9843
y = 0.0025x + 0.0444
R² = 0.981
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)

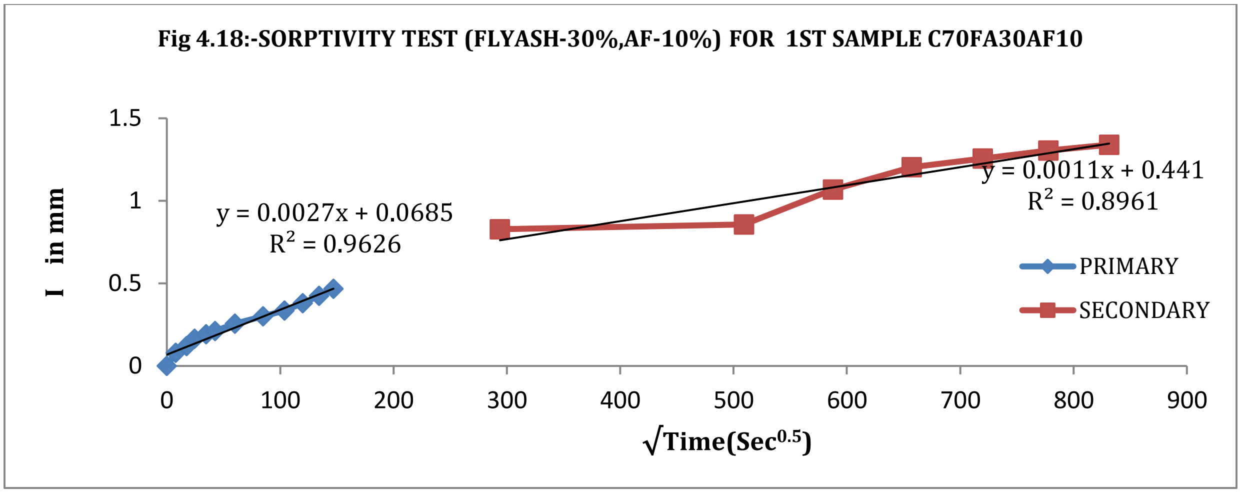


Fig 4.18:-SORPTIVITY TEST (FLYASH-30%,AF-10%) FOR 1ST SAMPLE C70FA30AF10
I in mm
1.5
1
0.5
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
y = 0.0027x + 0.0685
R² = 0.9626
y = 0.0011x + 0.441
R² = 0.8961
PRIMARY
SECONDARY

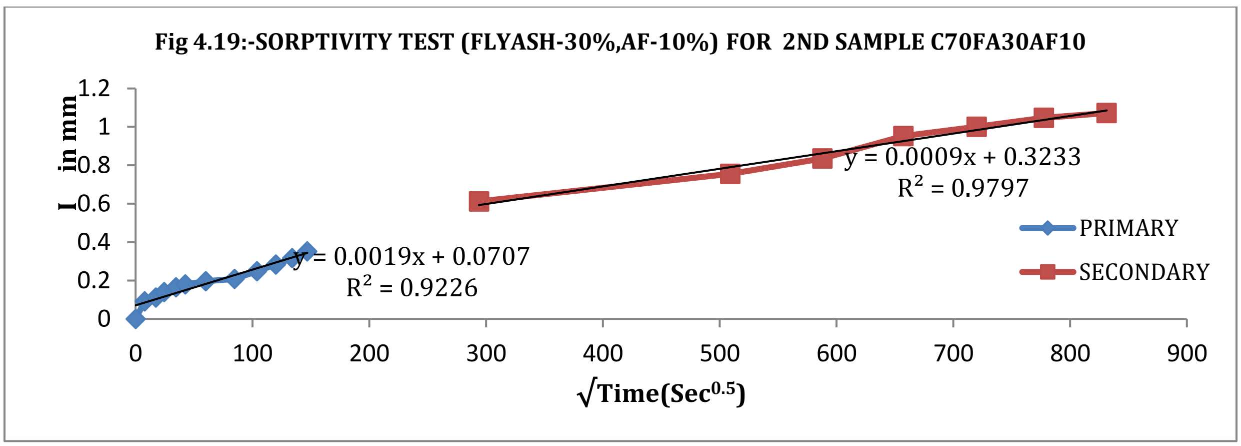


Fig 4.19:-SORPTIVITY TEST (FLYASH-30%,AF-10%) FOR 2ND SAMPLE C70FA30AF10
I in mm
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
y = 0.0019x + 0.0707
R² = 0.9226
y = 0.0009x + 0.3233
R² = 0.9797
PRIMARY
SECONDARY

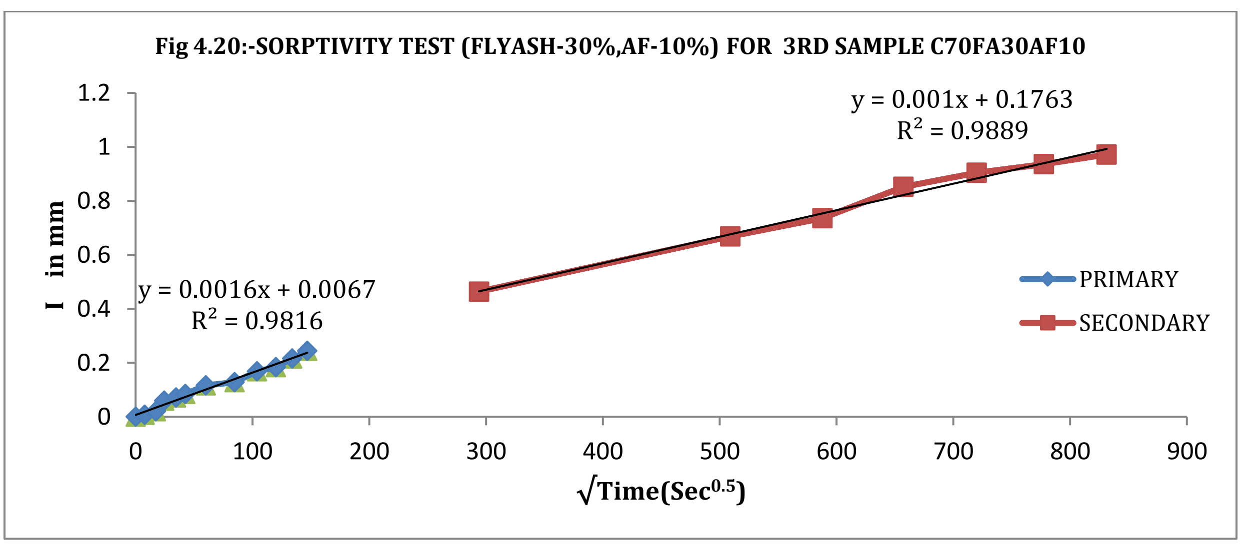


Fig 4.20:-SORPTIVITY TEST (FLYASH-30%,AF-10%) FOR 3RD SAMPLE C70FA30AF10
I in mm
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
y = 0.0016x + 0.0067
R² = 0.9816
y = 0.001x + 0.1763
R² = 0.9889
PRIMARY
SECONDARY

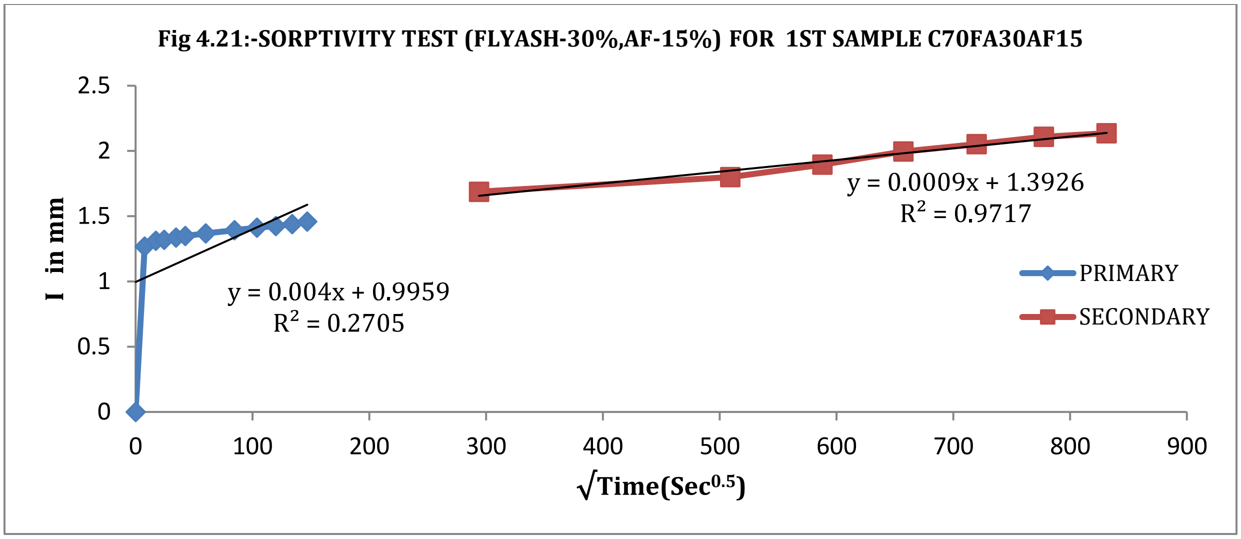


Fig 4.21:-SORPTIVITY TEST (FLYASH-30%,AF-15%) FOR 1ST SAMPLE C70FA30AF15
I in mm
√Time(Sec0.5)
y = 0.004x + 0.9959
R² = 0.2705
y = 0.0009x + 1.3926
R² = 0.9717
PRIMARY
SECONDARY

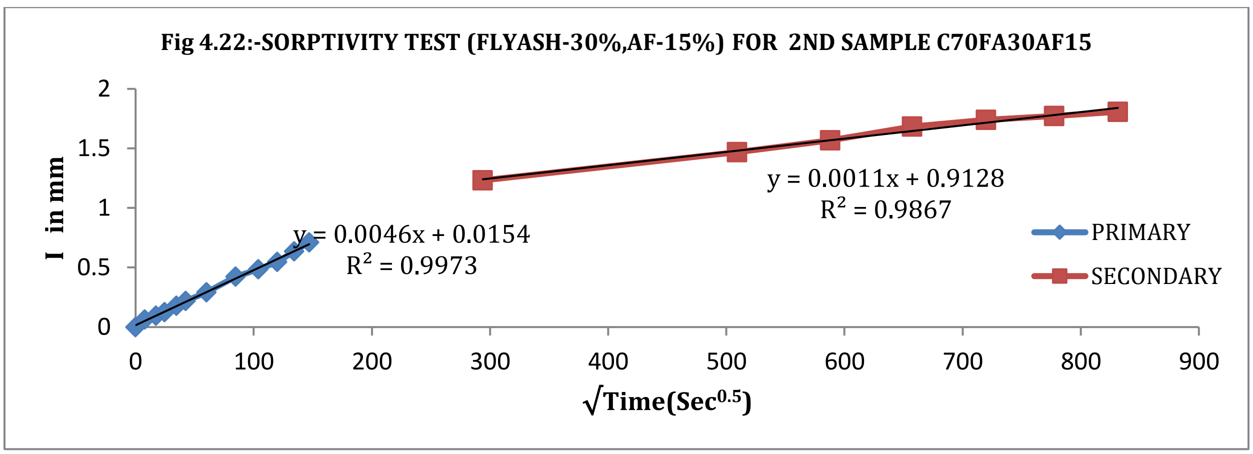


Fig 4.22:-SORPTIVITY TEST (FLYASH-30%,AF-15%) FOR 2ND SAMPLE C70FA30AF15
I in mm
√Time(Sec0.5)
y = 0.0046x + 0.0154
R² = 0.9973
y = 0.0011x + 0.9128
R² = 0.9867
PRIMARY
SECONDARY

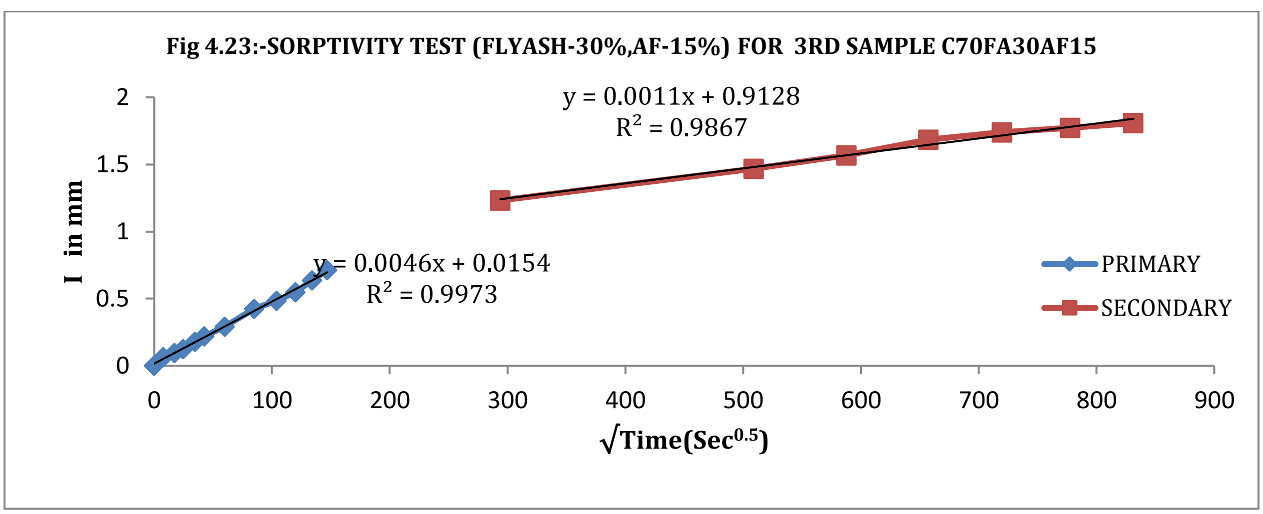


Fig 4.23:-SORPTIVITY TEST (FLYASH-30%,AF-15%) FOR 3RD SAMPLE C70FA30AF15
I in mm
√Time(Sec0.5)
y = 0.0011x + 0.9128
R² = 0.9867
y = 0.0046x + 0.0154
R² = 0.9973
PRIMARY
SECONDARY

Fig 4.24:-SORPTIVITY TEST (FLYASH-50%,AF-5%) FOR 1ST SAMPLE C50FA50AF5

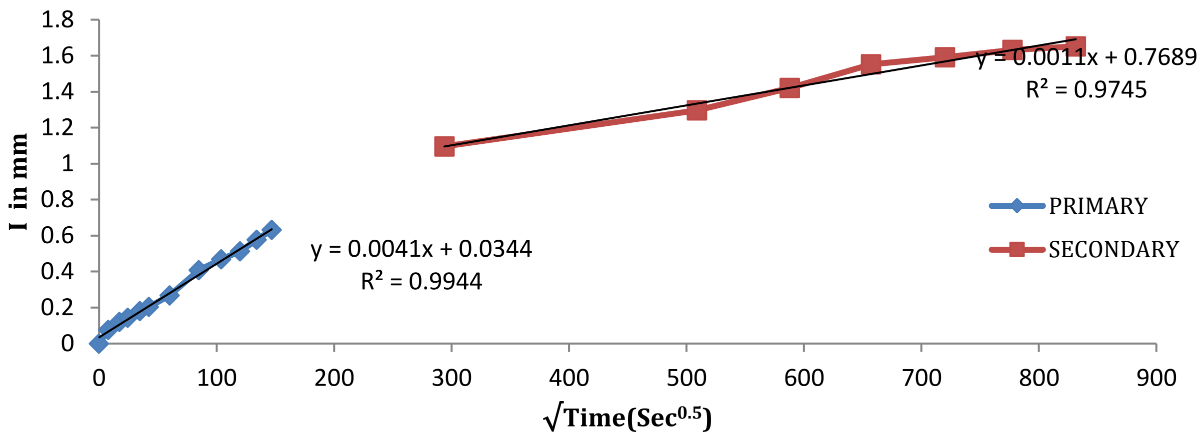


Fig 4.25:-SORPTIVITY TEST (FLYASH-50%,AF-5%) FOR 2ND SAMPLE C50FA50AF5

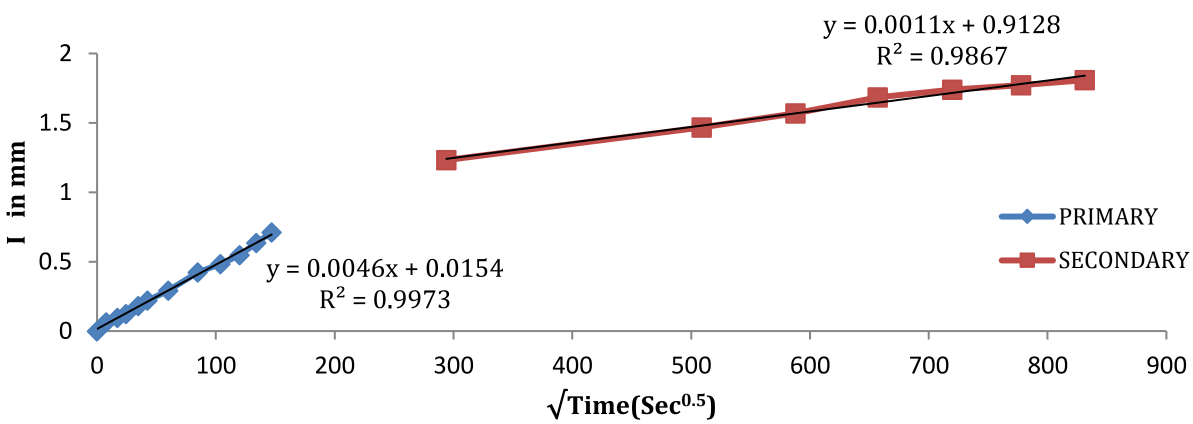
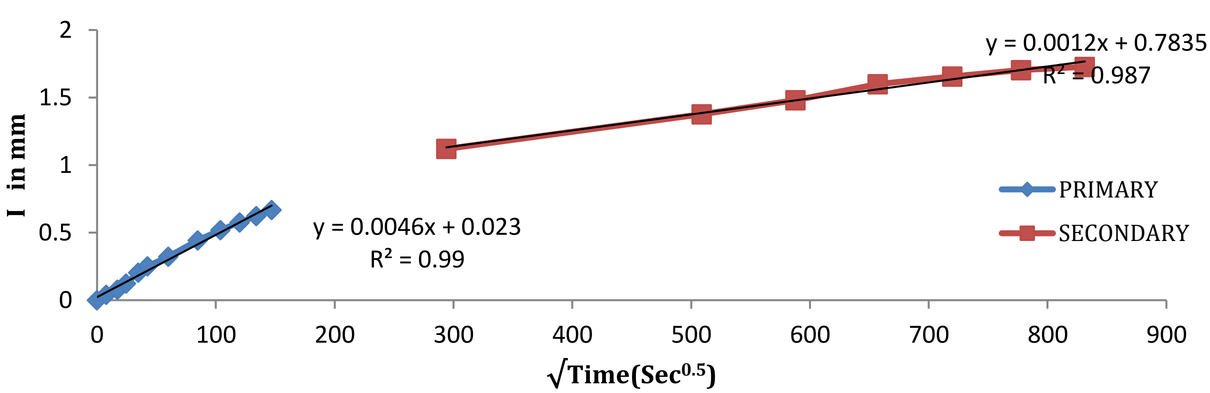


Fig 4.26:-SORPTIVITY TEST (FLYASH-50%,AF-5%) FOR 3RD SAMPLE C50FA50AF5



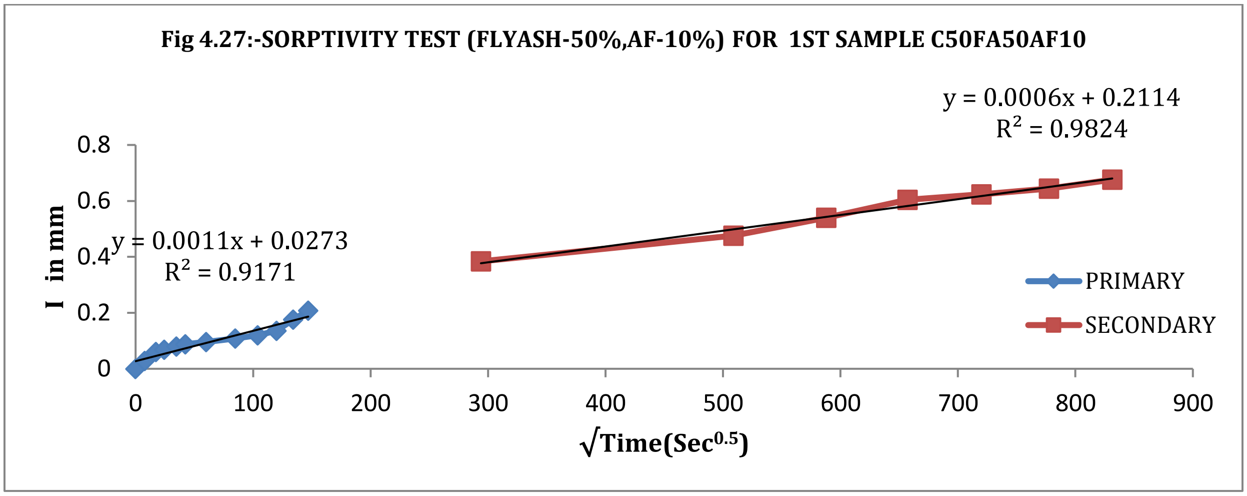


Fig 4.27:-SORPTIVITY TEST (FLYASH-50%,AF-10%) FOR 1ST SAMPLE C50FA50AF10
y = 0.0006x + 0.2114
R² = 0.9824
y = 0.0011x + 0.0273
R² = 0.9171
I in mm
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
PRIMARY
SECONDARY

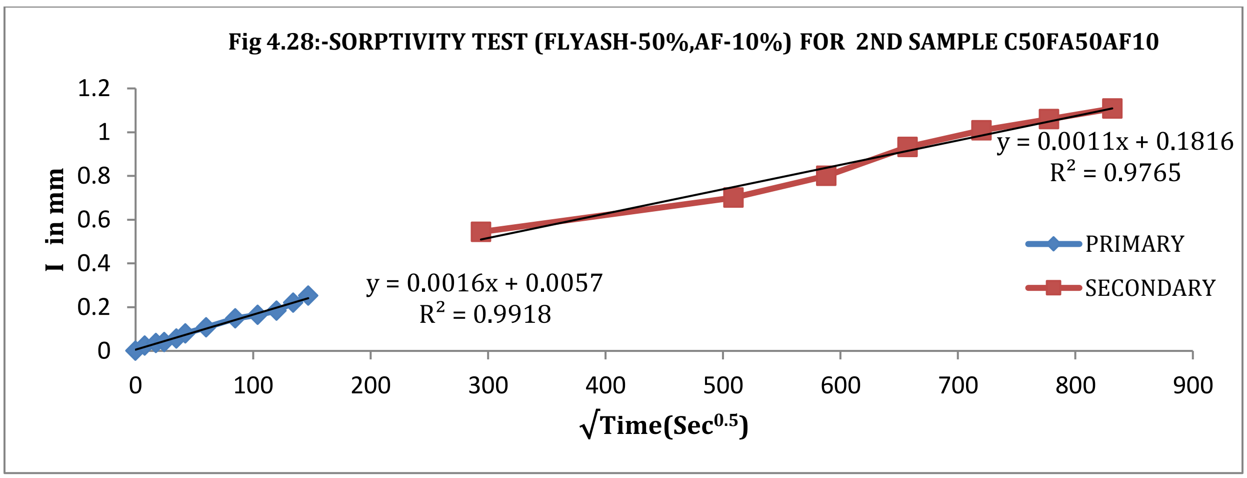


Fig 4.28:-SORPTIVITY TEST (FLYASH-50%,AF-10%) FOR 2ND SAMPLE C50FA50AF10
y = 0.0011x + 0.1816
R² = 0.9765
y = 0.0016x + 0.0057
R² = 0.9918
I in mm
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
PRIMARY
SECONDARY

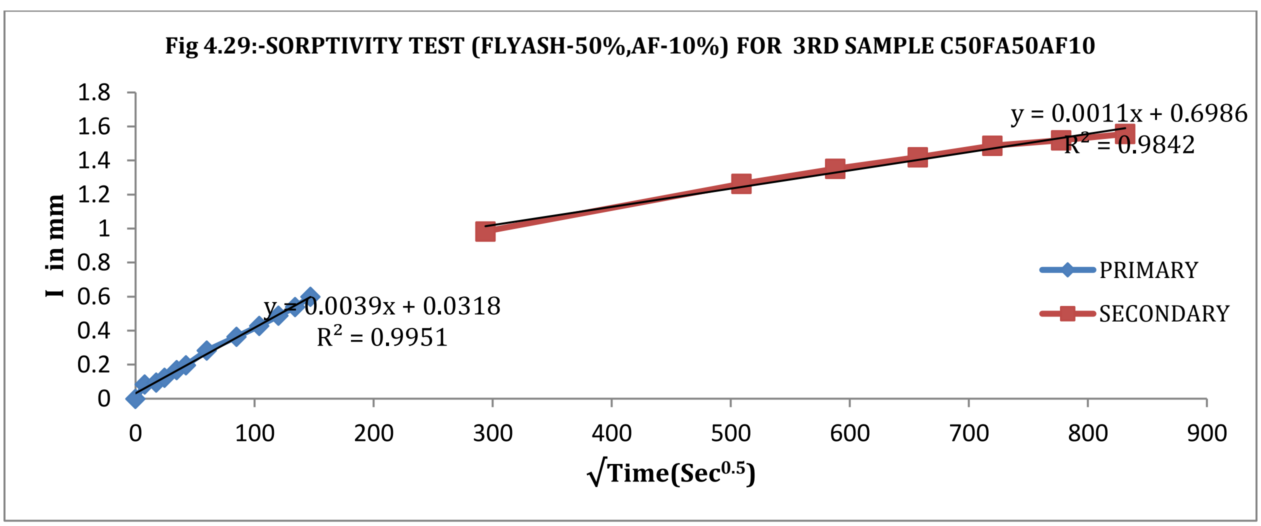


Fig 4.29:-SORPTIVITY TEST (FLYASH-50%,AF-10%) FOR 3RD SAMPLE C50FA50AF10
y = 0.0011x + 0.6986
R² = 0.9842
y = 0.0039x + 0.0318
R² = 0.9951
I in mm
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
√Time(Sec^0.5)
PRIMARY
SECONDARY

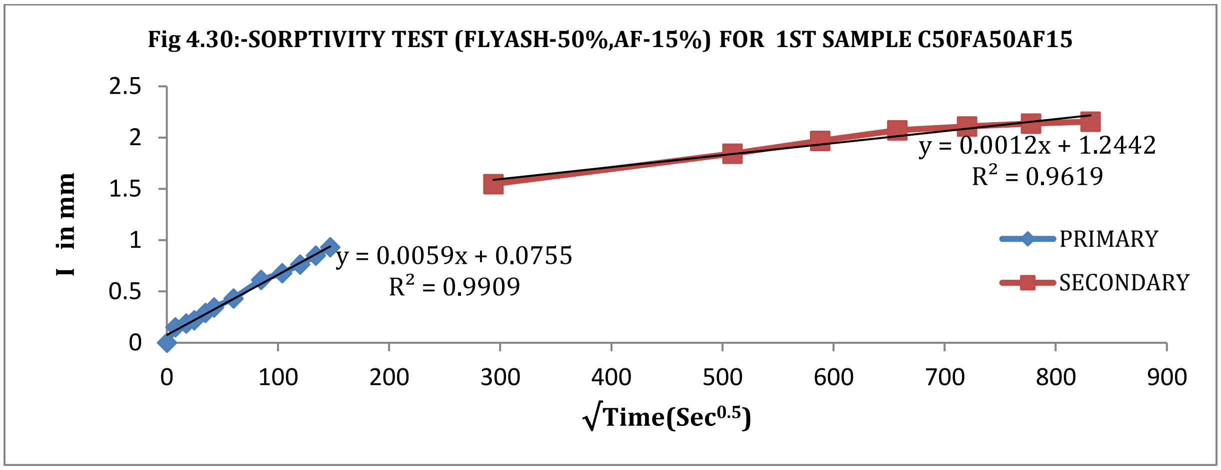


Fig 4.30:-SORPTIVITY TEST (FLYASH-50%,AF-15%) FOR 1ST SAMPLE C50FA50AF15
I in mm
√Time(Sec^0.5)
y = 0.0012x + 1.2442
R² = 0.9619
y = 0.0059x + 0.0755
R² = 0.9909
PRIMARY
SECONDARY
0
0.5
1
1.5
2
2.5
0
100
200
300
400
500
600
700
800
900

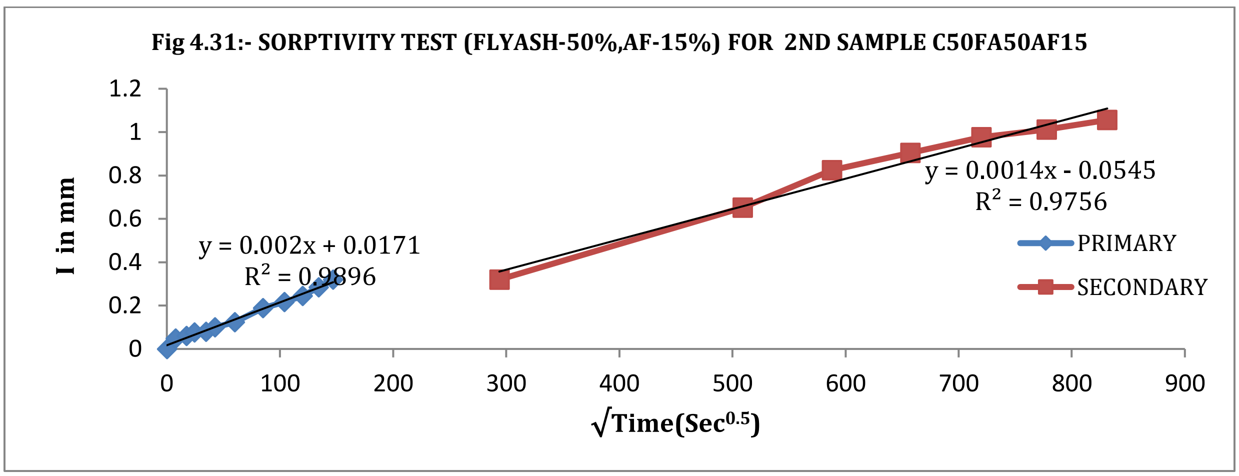


Fig 4.31:- SORPTIVITY TEST (FLYASH-50%,AF-15%) FOR 2ND SAMPLE C50FA50AF15
I in mm
√Time(Sec^0.5)
y = 0.0014x - 0.0545
R² = 0.9756
y = 0.002x + 0.0171
R² = 0.9896
PRIMARY
SECONDARY
0
0.2
0.4
0.6
0.8
1
1.2
0
100
200
300
400
500
600
700
800
900

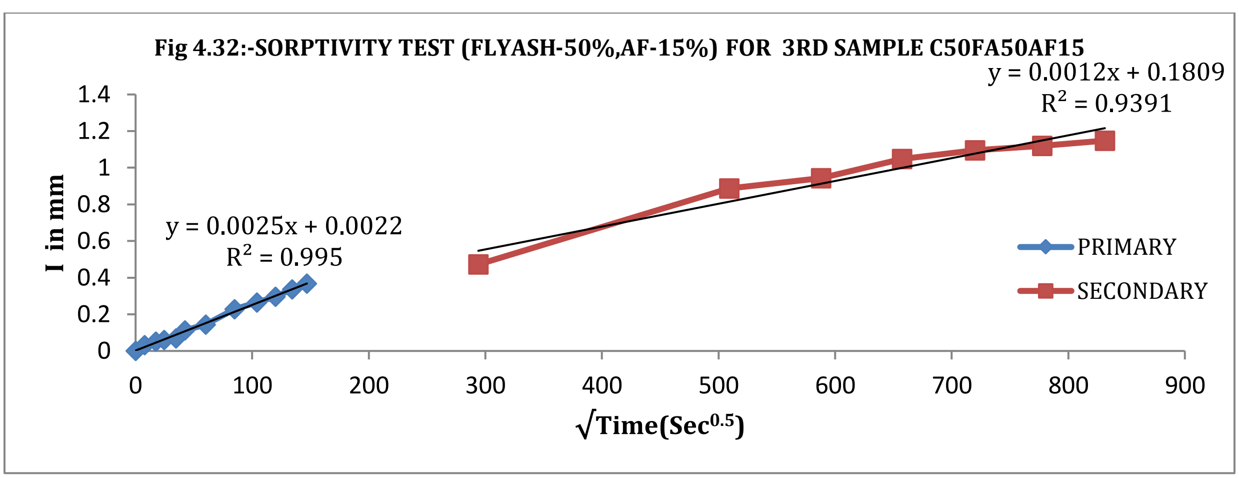


Fig 4.32:-SORPTIVITY TEST (FLYASH-50%,AF-15%) FOR 3RD SAMPLE C50FA50AF15
I in mm
√Time(Sec^0.5)
y = 0.0012x + 0.1809
R² = 0.9391
y = 0.0025x + 0.0022
R² = 0.995
PRIMARY
SECONDARY
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
100
200
300
400
500
600
700
800
900

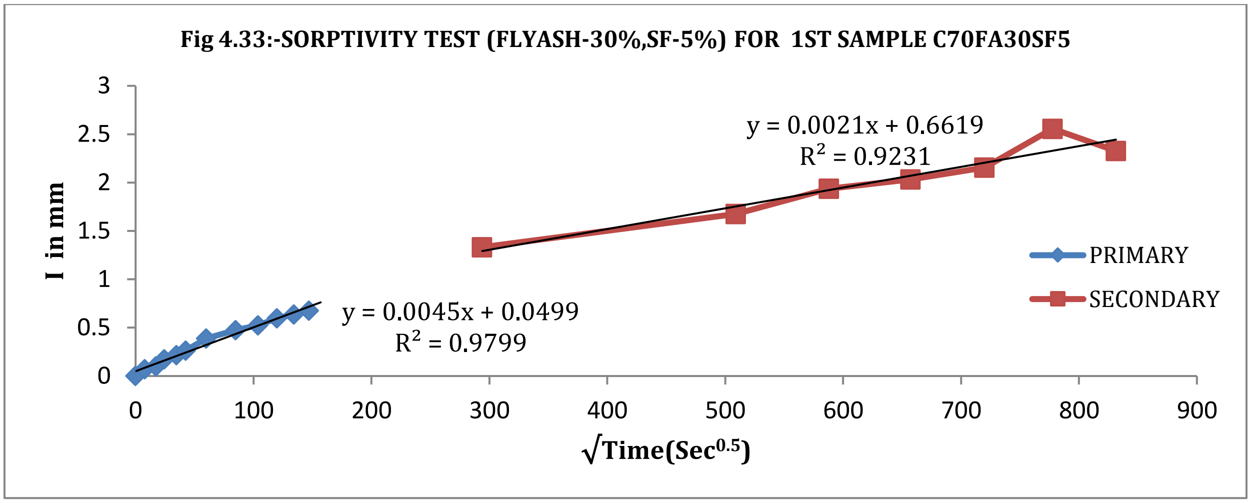


Fig 4.33:-SORPTIVITY TEST (FLYASH-30%,SF-5%) FOR 1ST SAMPLE C70FA30SF5
y = 0.0021x + 0.6619
R² = 0.9231
y = 0.0045x + 0.0499
R² = 0.9799
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)
0
0.5
1
1.5
2
2.5
3
100
200
300
400
500
600
700
800
900

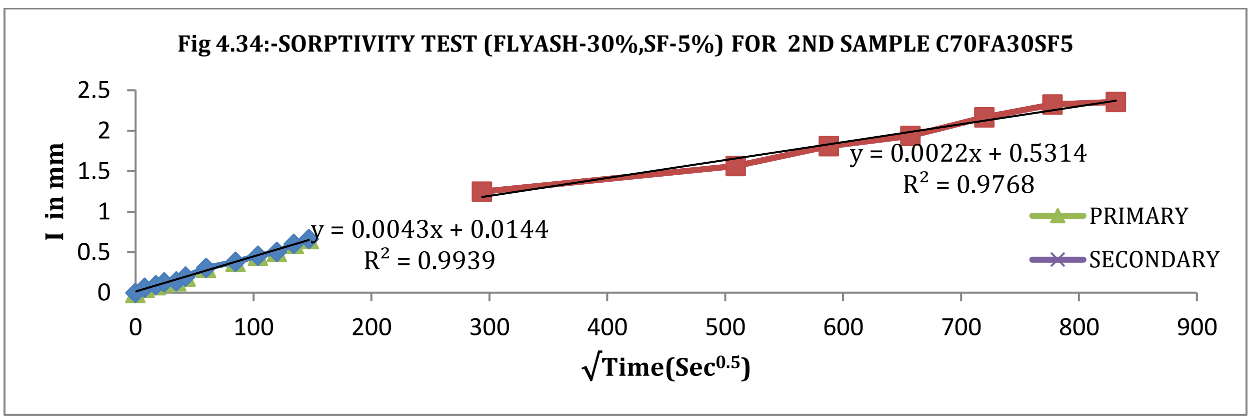


Fig 4.34:-SORPTIVITY TEST (FLYASH-30%,SF-5%) FOR 2ND SAMPLE C70FA30SF5
y = 0.0022x + 0.5314
R² = 0.9768
y = 0.0043x + 0.0144
R² = 0.9939
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)
0
0.5
1
1.5
2
2.5
100
200
300
400
500
600
700
800
900

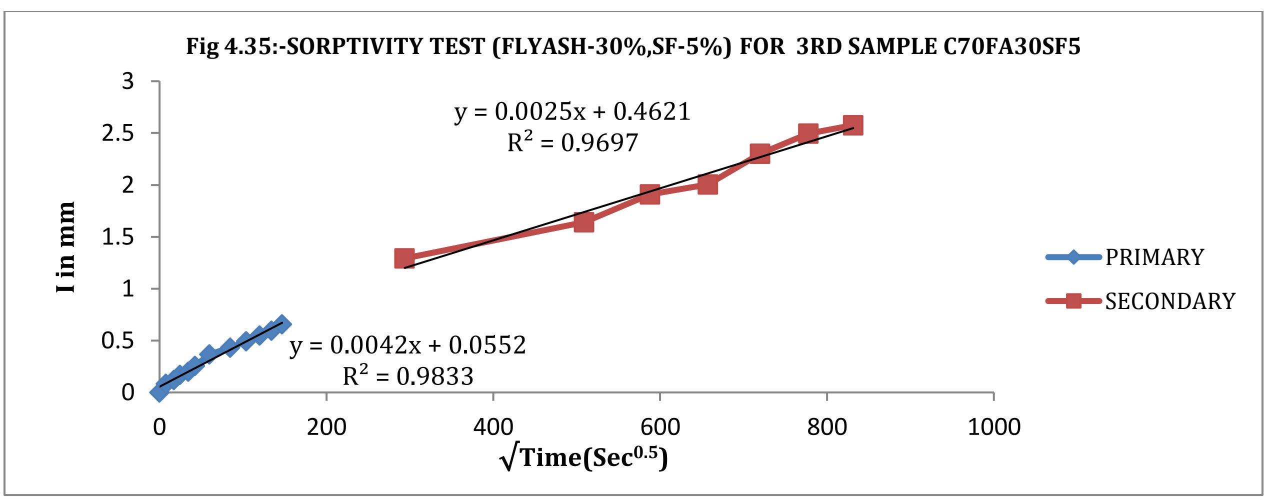


Fig 4.35:-SORPTIVITY TEST (FLYASH-30%,SF-5%) FOR 3RD SAMPLE C70FA30SF5
y = 0.0025x + 0.4621
R² = 0.9697
y = 0.0042x + 0.0552
R² = 0.9833
PRIMARY
SECONDARY
I in mm
√Time(Sec^0.5)
0
0.5
1
1.5
2
2.5
3
200
400
600
800
1000

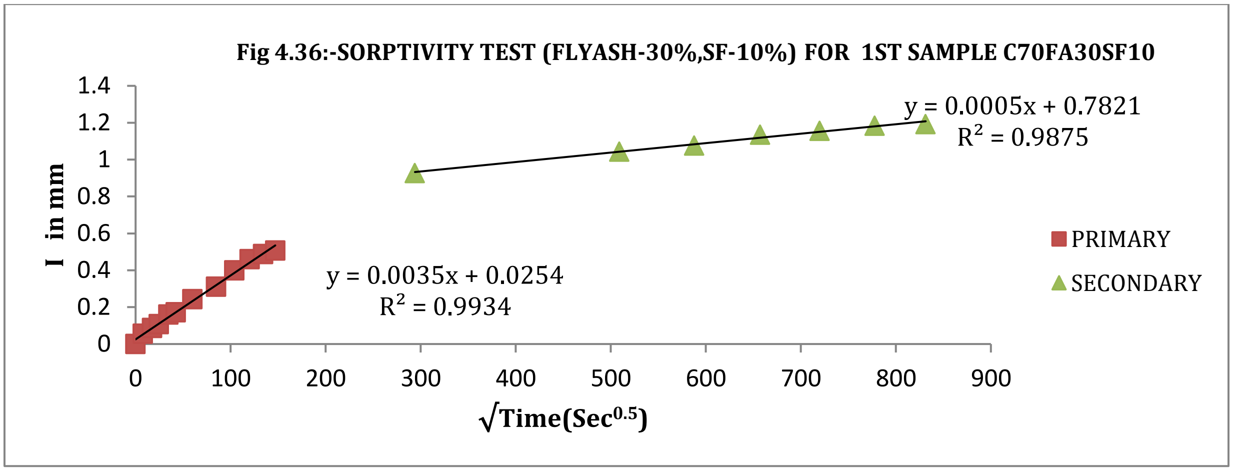


Fig 4.36:-SORPTIVITY TEST (FLYASH-30%,SF-10%) FOR 1ST SAMPLE C70FA30SF10
I in mm
√Time(Sec^0.5)
y = 0.0005x + 0.7821
R² = 0.9875
y = 0.0035x + 0.0254
R² = 0.9934
PRIMARY
SECONDARY
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
100
200
300
400
500
600
700
800
900

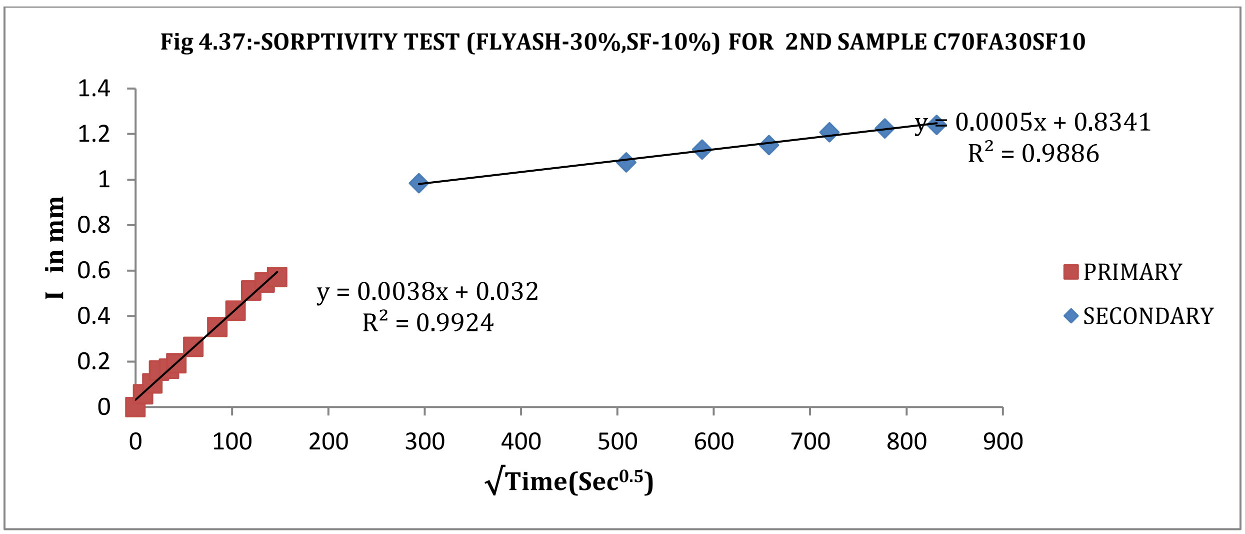


Fig 4.37:-SORPTIVITY TEST (FLYASH-30%,SF-10%) FOR 2ND SAMPLE C70FA30SF10
I in mm
√Time(Sec^0.5)
y = 0.0005x + 0.8341
R² = 0.9886
y = 0.0038x + 0.032
R² = 0.9924
PRIMARY
SECONDARY
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
100
200
300
400
500
600
700
800
900

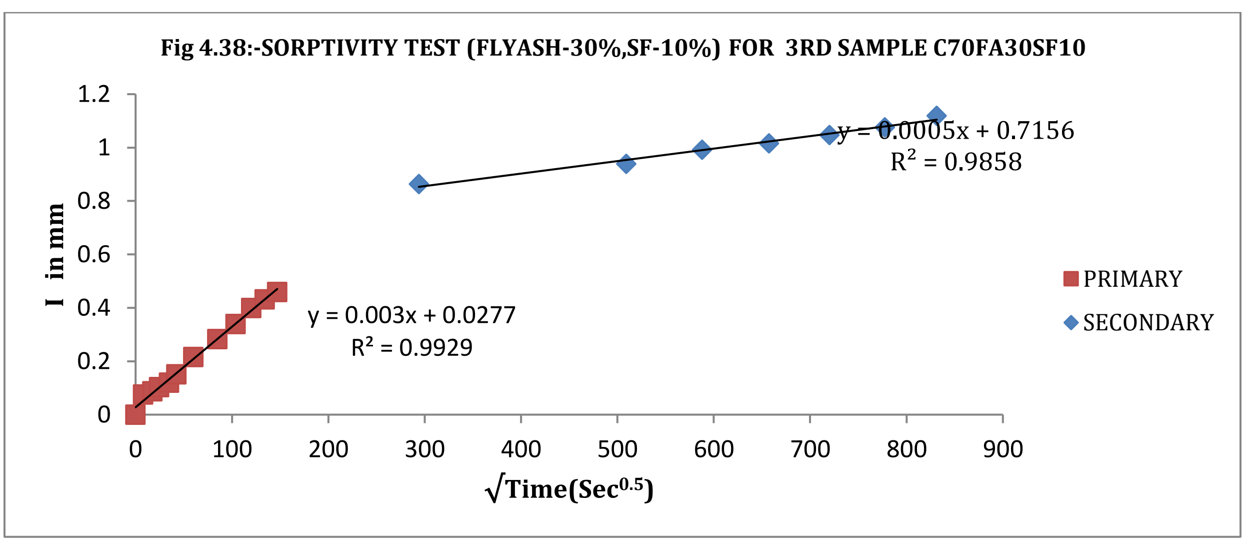


Fig 4.38:-SORPTIVITY TEST (FLYASH-30%,SF-10%) FOR 3RD SAMPLE C70FA30SF10
I in mm
√Time(Sec^0.5)
y = 0.0005x + 0.7156
R² = 0.9858
y = 0.003x + 0.0277
R² = 0.9929
PRIMARY
SECONDARY
0
0.2
0.4
0.6
0.8
1
1.2
0
100
200
300
400
500
600
700
800
900

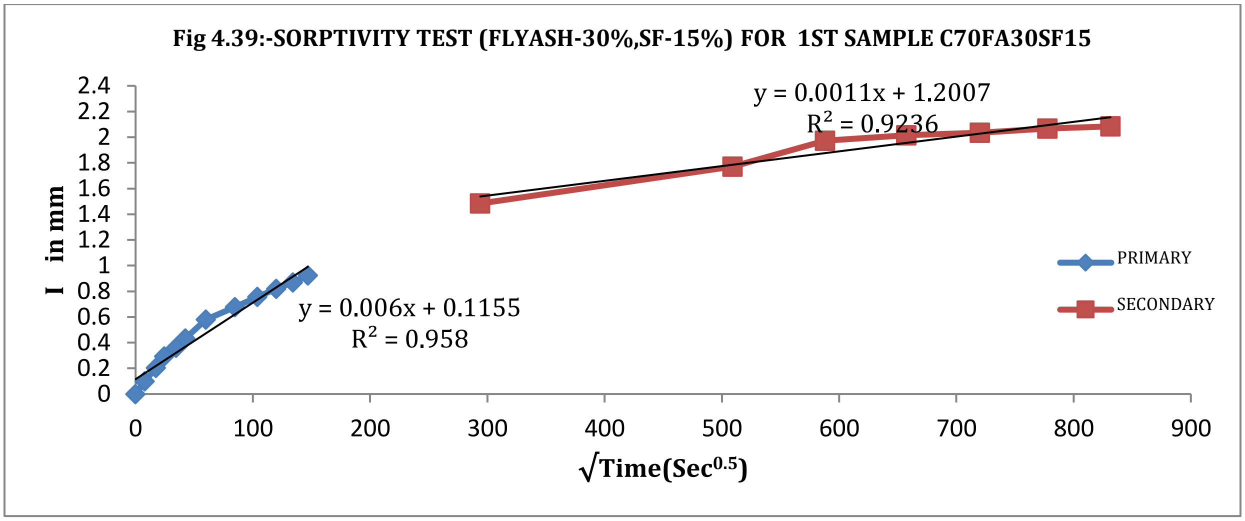


Fig 4.39:-SORPTIVITY TEST (FLYASH-30%,SF-15%) FOR 1ST SAMPLE C70FA30SF15
y = 0.0011x + 1.2007
R² = 0.9236
y = 0.006x + 0.1155
R² = 0.958
PRIMARY
SECONDARY
I in mm
√Time(Sec0.5)

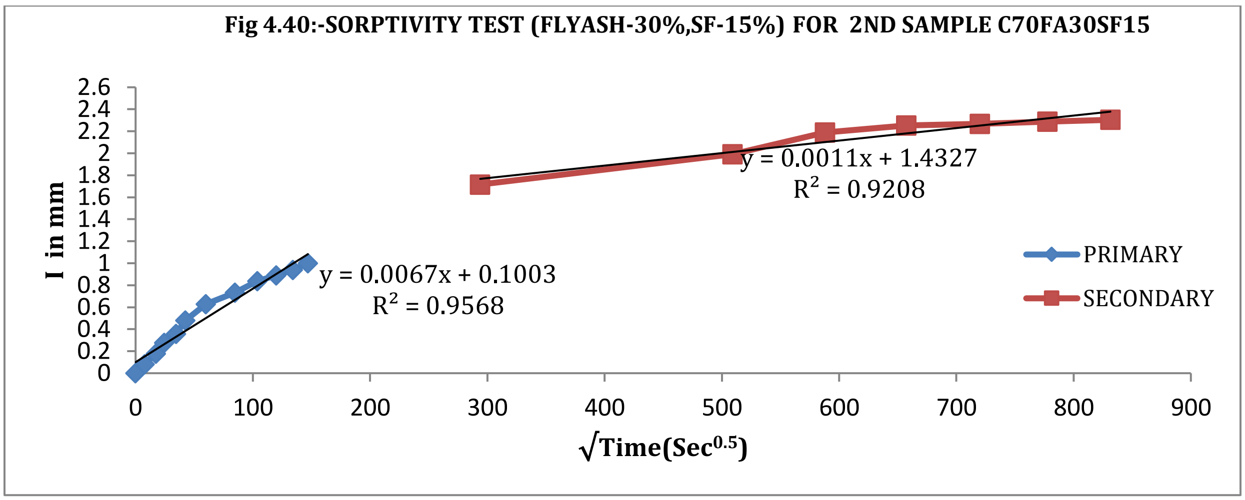


Fig 4.40:-SORPTIVITY TEST (FLYASH-30%,SF-15%) FOR 2ND SAMPLE C70FA30SF15
y = 0.0011x + 1.4327
R² = 0.9208
y = 0.0067x + 0.1003
R² = 0.9568
PRIMARY
SECONDARY
I in mm
√Time(Sec0.5)

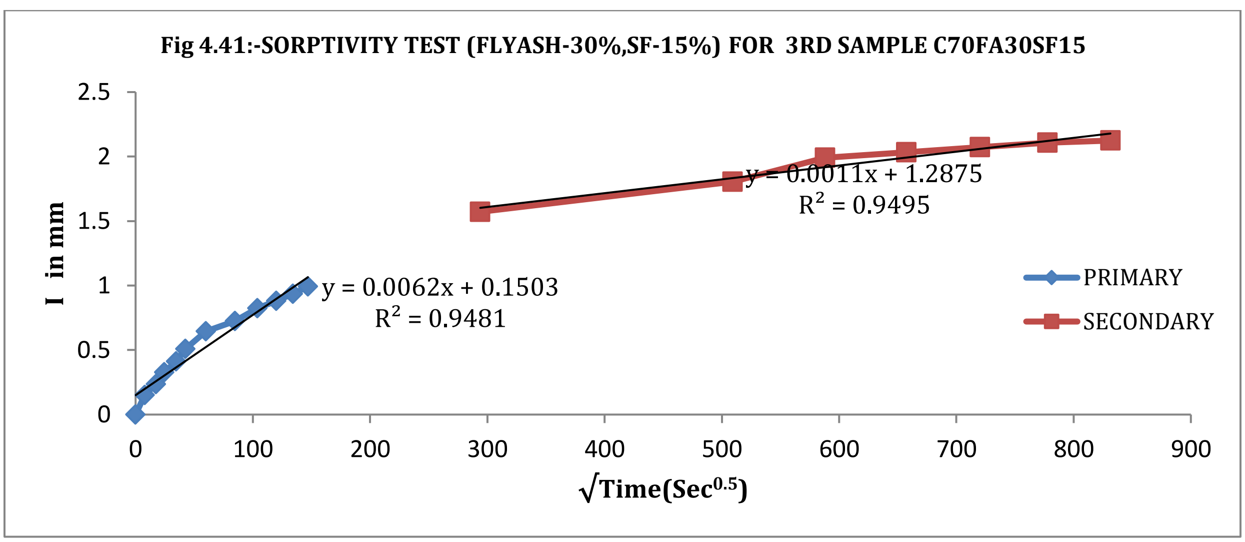


Fig 4.41:-SORPTIVITY TEST (FLYASH-30%,SF-15%) FOR 3RD SAMPLE C70FA30SF15
y = 0.0011x + 1.2875
R² = 0.9495
y = 0.0062x + 0.1503
R² = 0.9481
PRIMARY
SECONDARY
I in mm
√Time(Sec0.5)

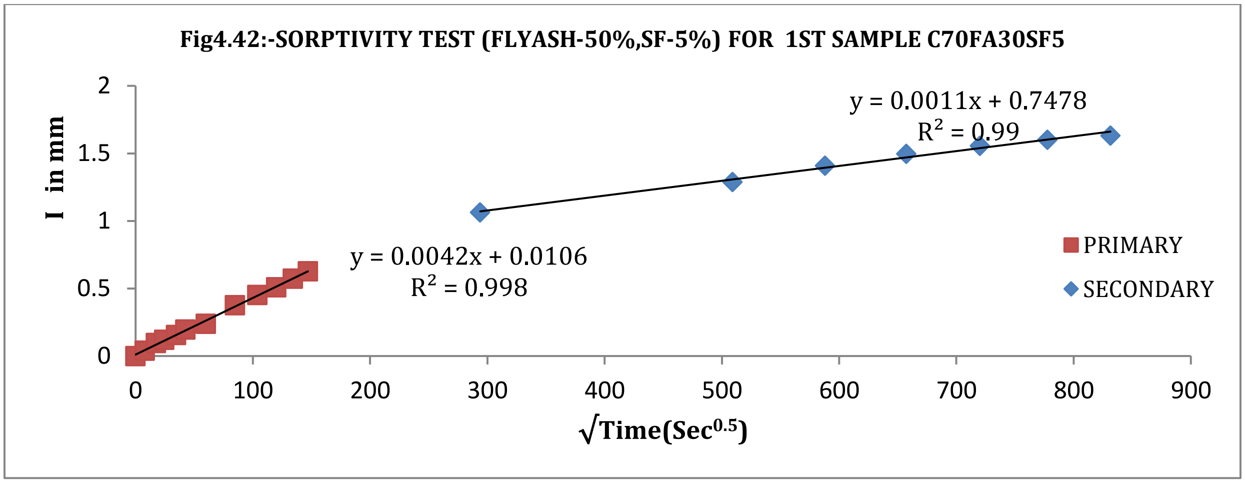


Fig4.42:-SORPTIVITY TEST (FLYASH-50%,SF-5%) FOR 1ST SAMPLE C70FA30SF5
I in mm
√Time(Sec0.5)
y = 0.0011x + 0.7478
R² = 0.99
y = 0.0042x + 0.0106
R² = 0.998
PRIMARY
SECONDARY

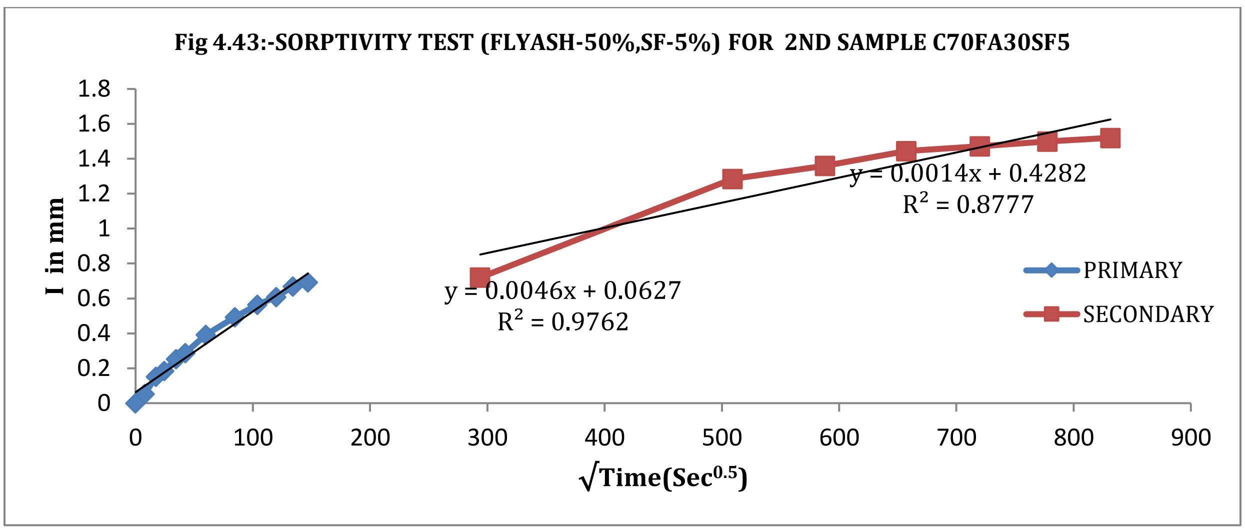


Fig 4.43:-SORPTIVITY TEST (FLYASH-50%,SF-5%) FOR 2ND SAMPLE C70FA30SF5
I in mm
√Time(Sec0.5)
y = 0.0014x + 0.4282
R² = 0.8777
y = 0.0046x + 0.0627
R² = 0.9762
PRIMARY
SECONDARY

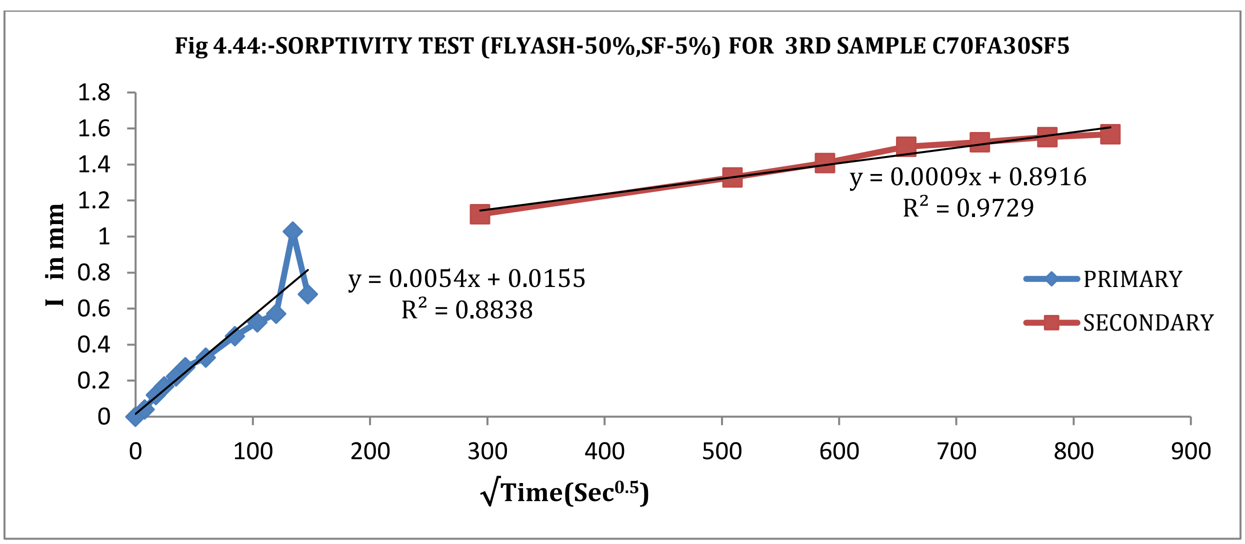


Fig 4.44:-SORPTIVITY TEST (FLYASH-50%,SF-5%) FOR 3RD SAMPLE C70FA30SF5
I in mm
√Time(Sec0.5)
y = 0.0009x + 0.8916
R² = 0.9729
y = 0.0054x + 0.0155
R² = 0.8838
PRIMARY
SECONDARY

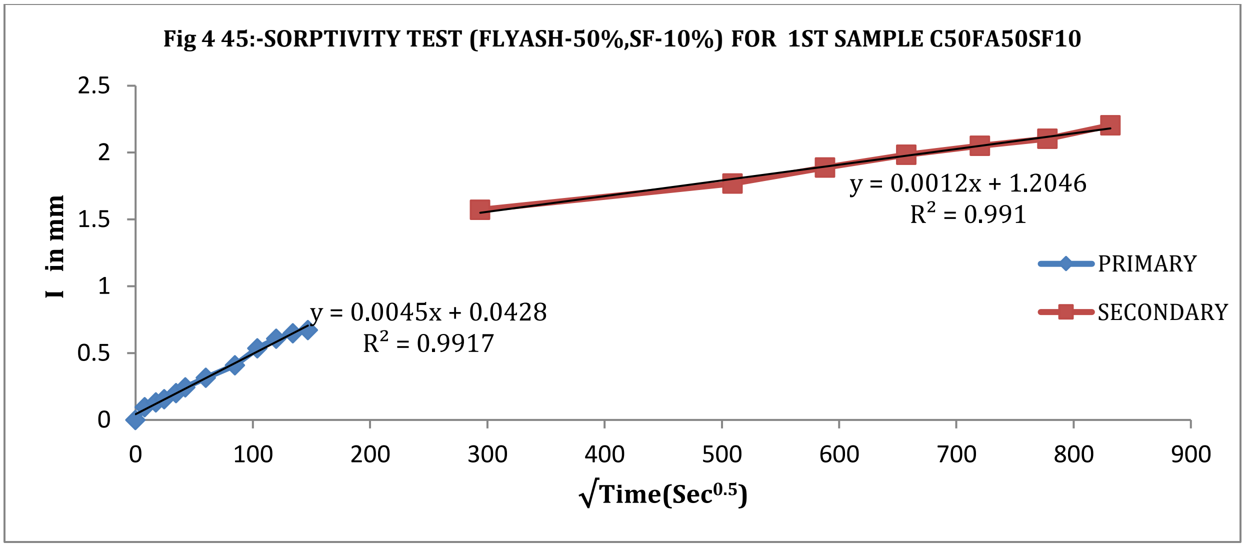


Fig 4 45:-SORPTIVITY TEST (FLYASH-50%,SF-10%) FOR 1ST SAMPLE C50FA50SF10
I in mm
√Time(Sec0.5)
y = 0.0012x + 1.2046
R² = 0.991
y = 0.0045x + 0.0428
R² = 0.9917
PRIMARY
SECONDARY

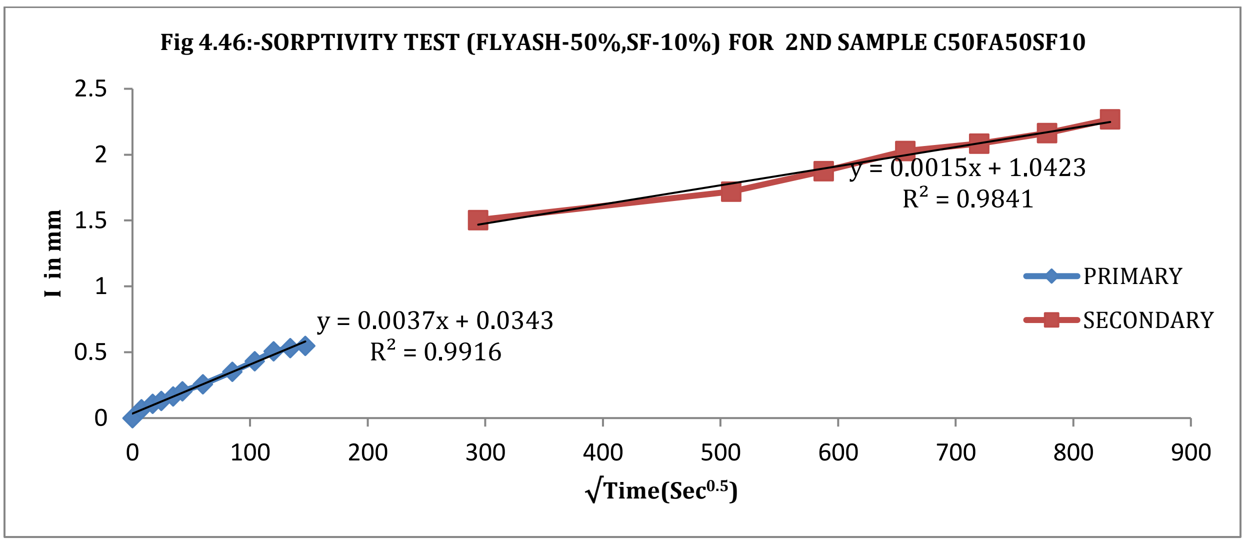


Fig 4.46:-SORPTIVITY TEST (FLYASH-50%,SF-10%) FOR 2ND SAMPLE C50FA50SF10
I in mm
√Time(Sec0.5)
y = 0.0015x + 1.0423
R² = 0.9841
y = 0.0037x + 0.0343
R² = 0.9916
PRIMARY
SECONDARY

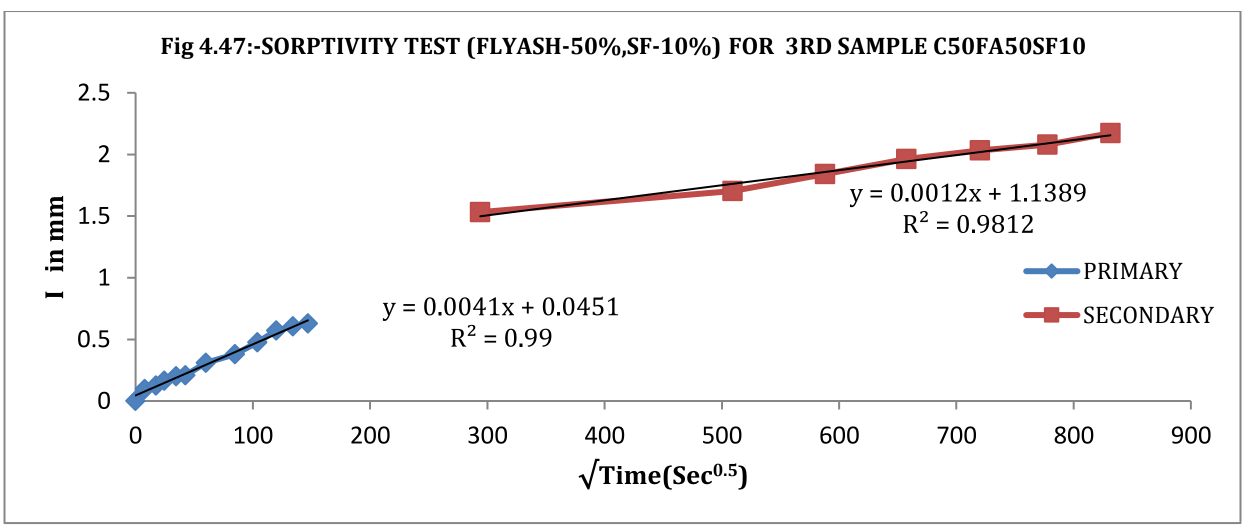


Fig 4.47:-SORPTIVITY TEST (FLYASH-50%,SF-10%) FOR 3RD SAMPLE C50FA50SF10
I in mm
√Time(Sec0.5)
y = 0.0012x + 1.1389
R² = 0.9812
y = 0.0041x + 0.0451
R² = 0.99
PRIMARY
SECONDARY

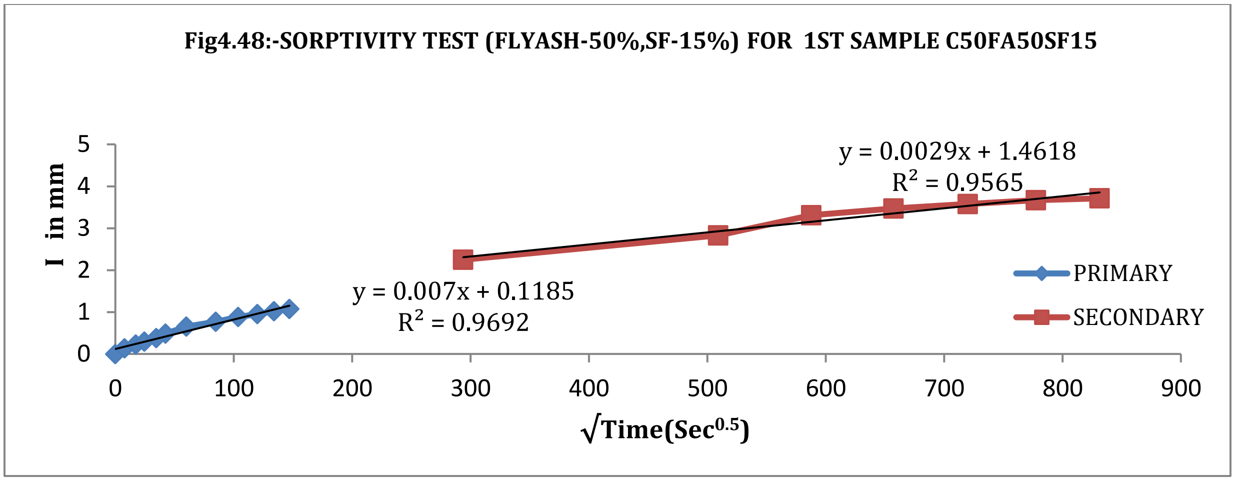


Fig4.48:-SORPTIVITY TEST (FLYASH-50%,SF-15%) FOR 1ST SAMPLE C50FA50SF15
I in mm
√Time(Sec^0.5)
y = 0.0029x + 1.4618
R² = 0.9565
y = 0.007x + 0.1185
R² = 0.9692
PRIMARY
SECONDARY

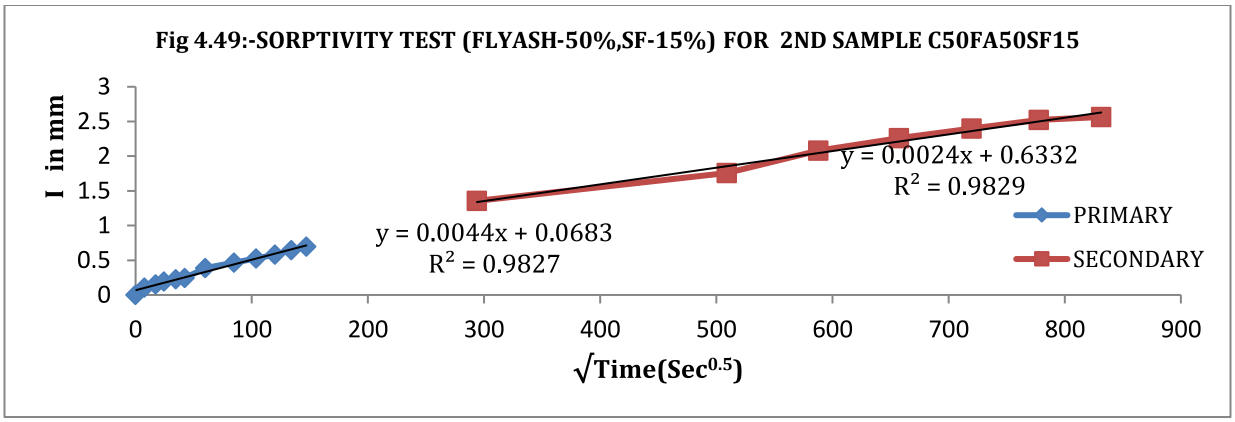


Fig 4.49:-SORPTIVITY TEST (FLYASH-50%,SF-15%) FOR 2ND SAMPLE C50FA50SF15
I in mm
√Time(Sec^0.5)
y = 0.0024x + 0.6332
R² = 0.9829
y = 0.0044x + 0.0683
R² = 0.9827
PRIMARY
SECONDARY

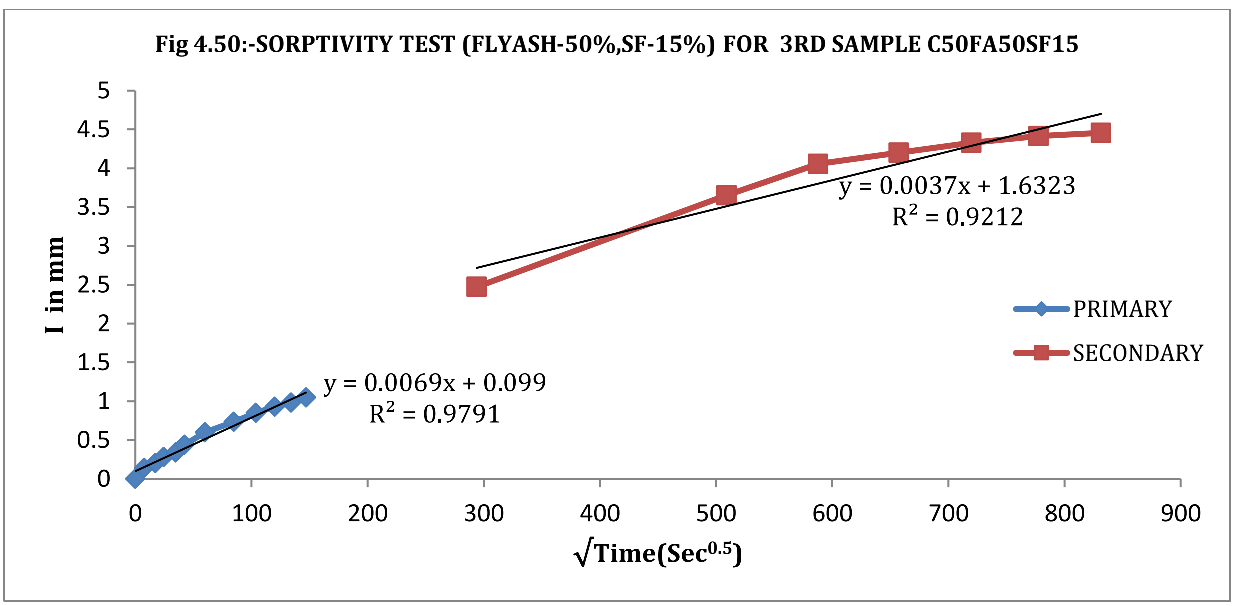


Fig 4.50:-SORPTIVITY TEST (FLYASH-50%,SF-15%) FOR 3RD SAMPLE C50FA50SF15
I in mm
√Time(Sec^0.5)
y = 0.0037x + 1.6323
R² = 0.9212
y = 0.0069x + 0.099
R² = 0.9791
PRIMARY
SECONDARY

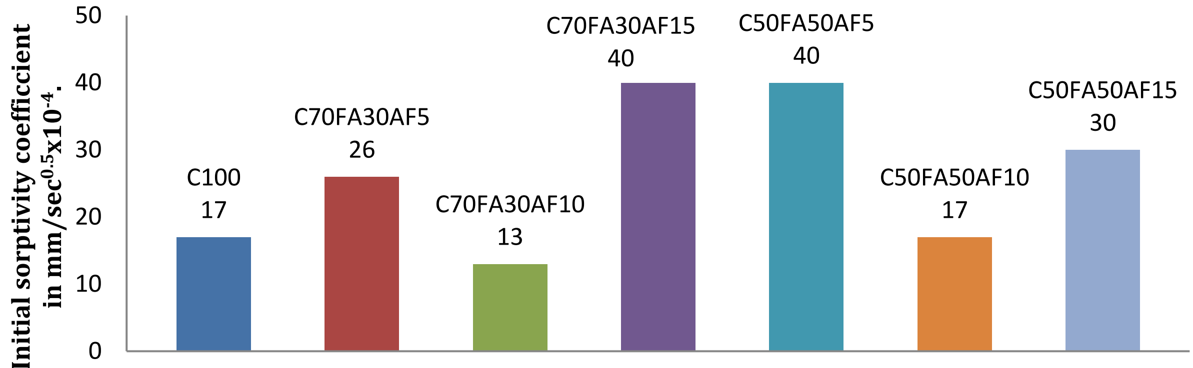


Fig 4.51 Comparision of Initial sorptivity in mm/sec$^{0.5}$ for mix contains various % of Flyash and Alcofine with the control mix.

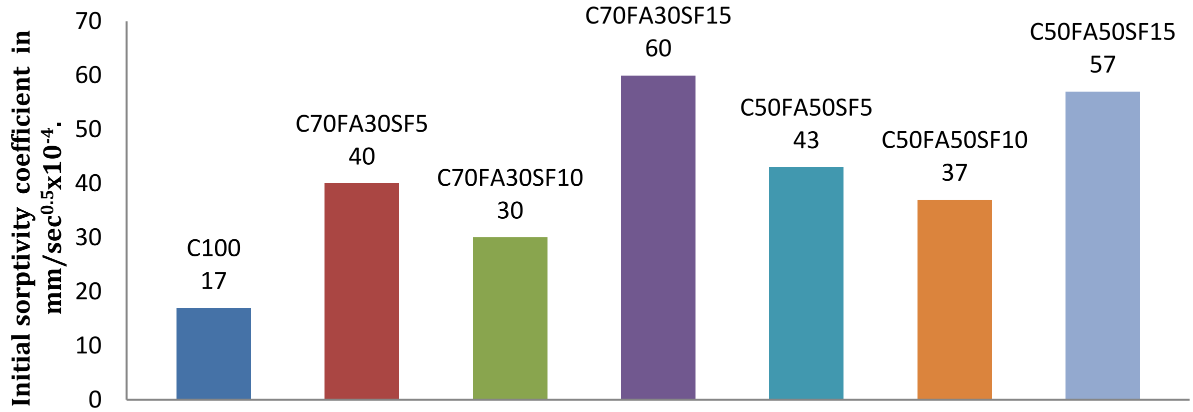


Fig 4.52 Comparision of Initial sorptivity in mm/sec$^{0.5}$ for mix contains various % of Flyash and Silicafume with the control mix.

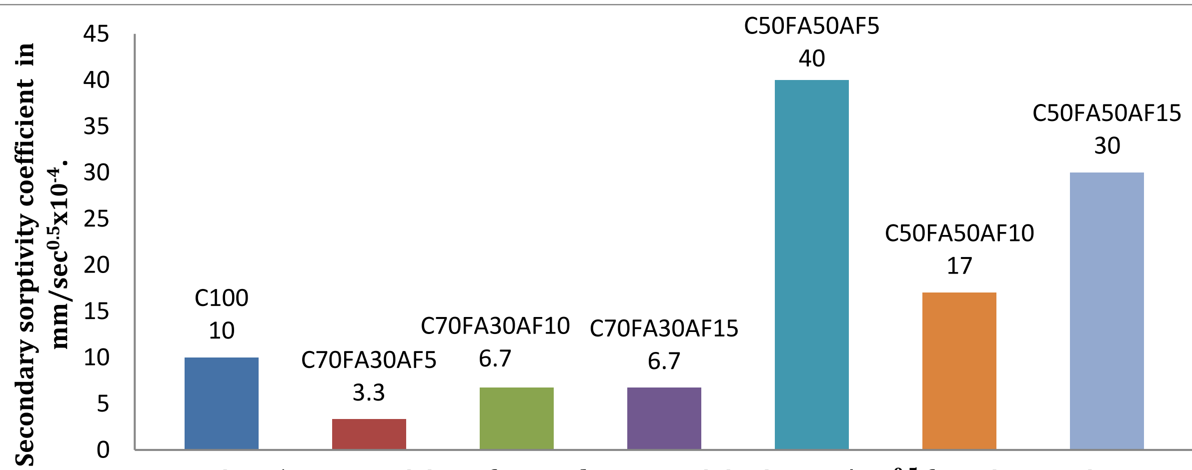


Fig 4.53 Comparision of Secondary Sorptivity in mm/sec$^{0.5}$ for mix contains various % of Flyash and Alcofine with the control mix.

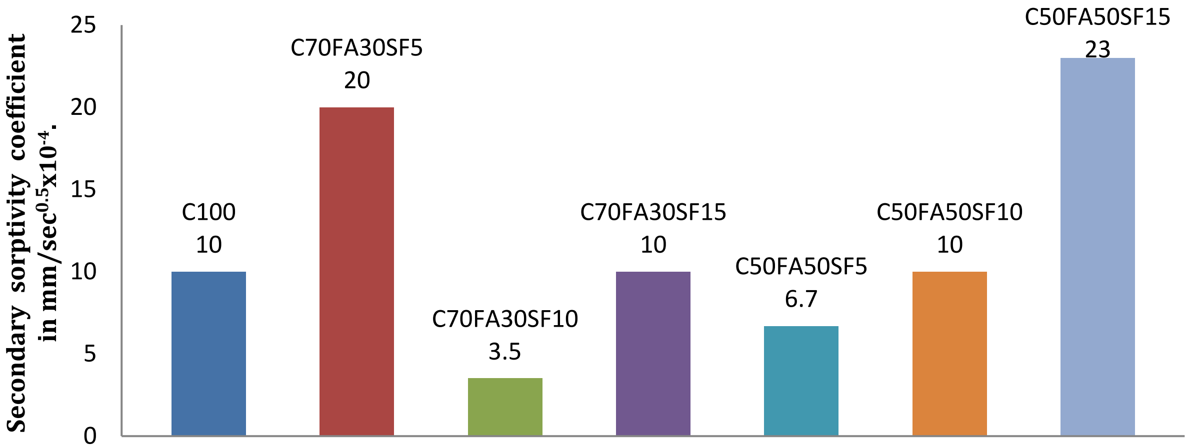


Fig 4.54Comparision of Secondary Sorptivity in mm/sec$^{0.5}$ for mix contains various % of Flyash and Silicafume with the control mix.

Discussions:-

From the results of initial Sorptivity it can be observed that there is not much contribution in improving the sorptivity of both the mixes comprising of alccofine, Silicafume and flyash in comparison to the control mix, which may be the reason for slow rate of hydration reaction property of flyash resulting in lesser formation of C-S-H gel matrix resulting in the creation of more pores, but in viewing the secondary sorptivity results it may be attributed that there is substantial improvement in secondary sorptivity of the mix contains alccofine in the range of 5% to 15% with flyash replacement level of 30% , where best performing sample in terms of secondary sorptivity is C70FA30AF5, which indicates the densifications and filling of internal pore network. In case of mix containing Silicafume there is not much improvement in secondary sorptivity of the mix except C70FA30SF10.

4.7 Compressive Strength:-

Compressive strength of a material is defined as its resistance to compressive load, for concrete it's an important hardened property to define its serviceability. The current sections presents the results of compressive strength test conducted by the method confirming to **ASTMC579** for 7 days and 28 days for various types of mix.

TABLE 4.6			
COMPRESSIVE STRENGTH RESULTS OF THE MIX			
W/C-0.36			
SL NO	**Mix type**	**AVERAGE 7 DAYS COMPRESSIVE STRENGTH(MPa)**	**AVERAGE 28 DAYS COMPRESSIVE STRENGTH(MPa)**
1	**C100**	38.67	46.67
2	**C70FA30AF5**	30.13	39.2
3	**C70FA30AF10**	27.3	45.06
4	**C70FA30AF15**	28	44
5	**C50FA50AF5**	23	36
6	**C50FA50AF10**	20.8	48
7	**C50FA50AF15**	21.5	37.3
8	**C50FA30SF5**	21.6	47.4
9	**C70FA30SF10**	28.3	54
10	**C70FA30SF15**	30.1	40.3
11	**C50FA50SF5**	18.4	36.8
12	**C50FA50SF10**	24.8	34.7
13	**C50FA50SF15**	22.67	44.3

Fig 4.55 Compressive strength test setup.

4.7.1 7 days Compressive Strength results:-

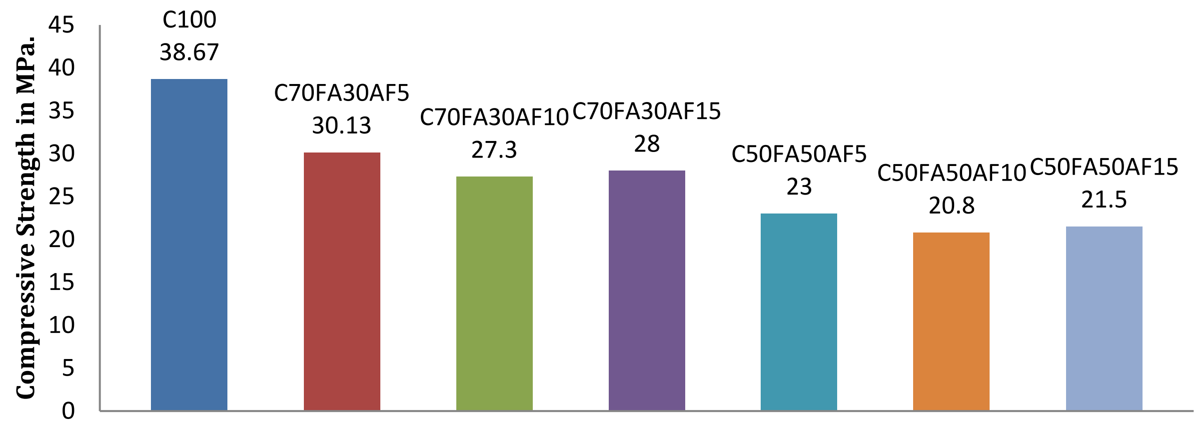


Fig 4.56 Comparision of 7 Days Compressive strength in MPa for mix contains various % of Flyash and Alccofine with the control mix.

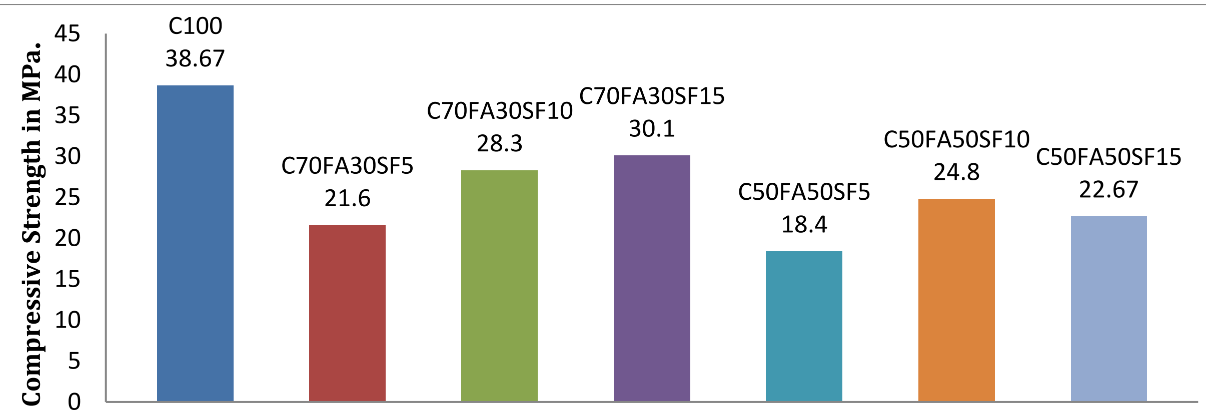


Fig 4.57 Comparision of 7 Days Compressive strength in MPa for mix contains various % of Flyash and Silicafume with the control mix.

Discussions

[6]Alccofine and Silicafume has a high early age strength, [3] which is reverse in case of flyash. From the results obtained it may said that with percentage increase of alcofine and 30 % flyash replacement the strength is decreasing, maximum at a replacement level of 5% alccofine and 30% flyash, which is 22.08% less than the control mix, similarly for Silicafume strength is increasing substantially with percentage increase in silica fume gives maximum results at a replacement level of 15% silica fume and 30% flyash which is 22.16% less than the control mix , [7]which can be attributed to the less reactive nature of flyash.

4.7.2 28 days Compressive strength:-

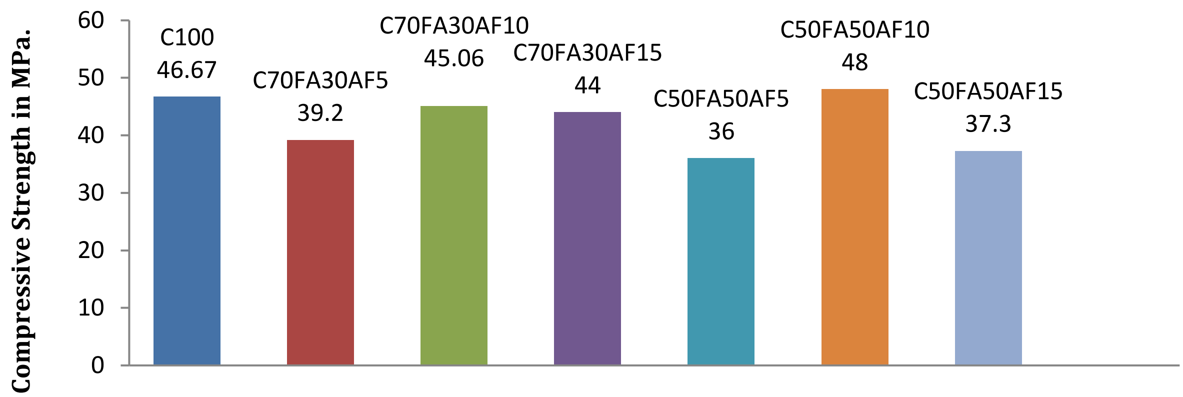


Fig 4.58 Comparision of 28 Days Compressive strength in MPa for mix contains various % of Flyash and Alccofine with the control mix.

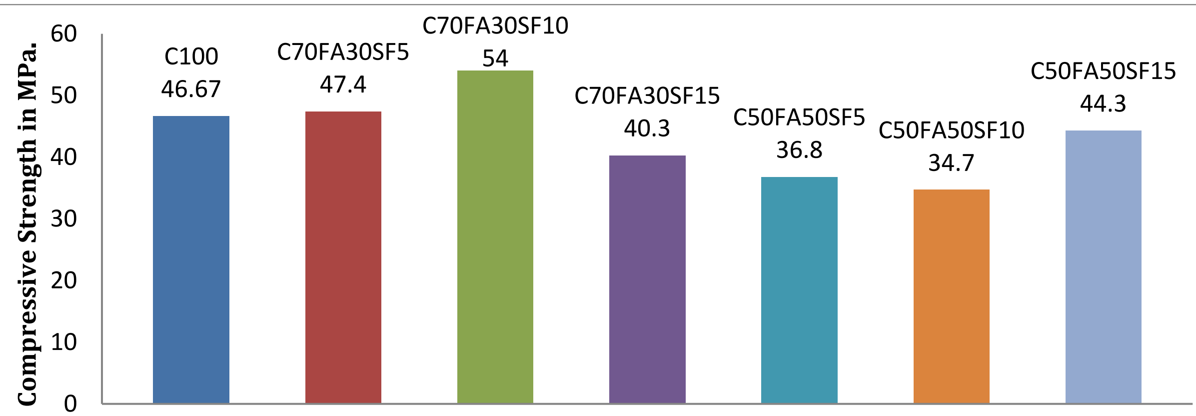


Fig 4.59 Comparision of 28 Days Compressive strength in MPa for mix contains various % of Flyash and Silicafume with the control mix.

4.7.3 Microstructure analysis of 28 days Compressive strength through SEM& EDS:-

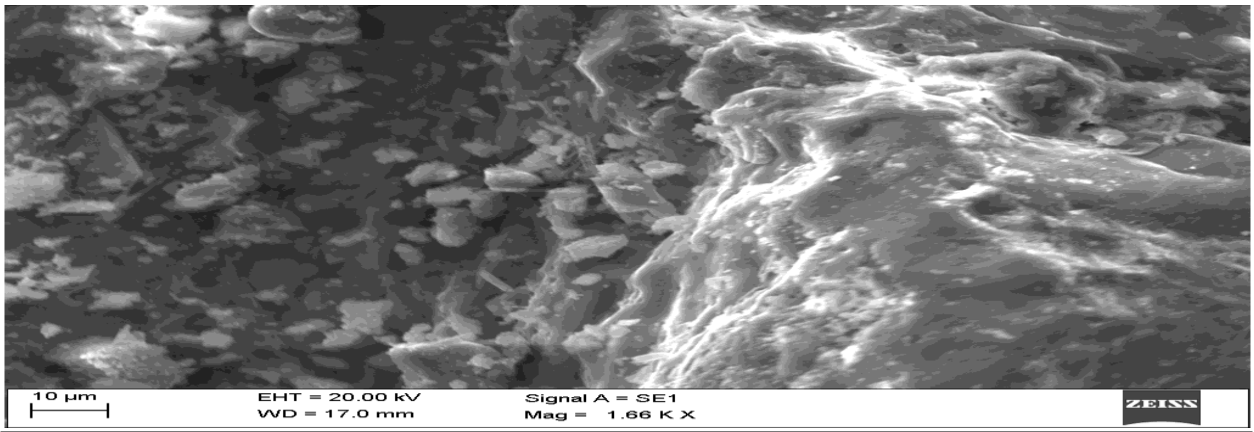


Fig 4.60 SEM image of 28 days Compressive strength test control mix sample tested at 1660X.

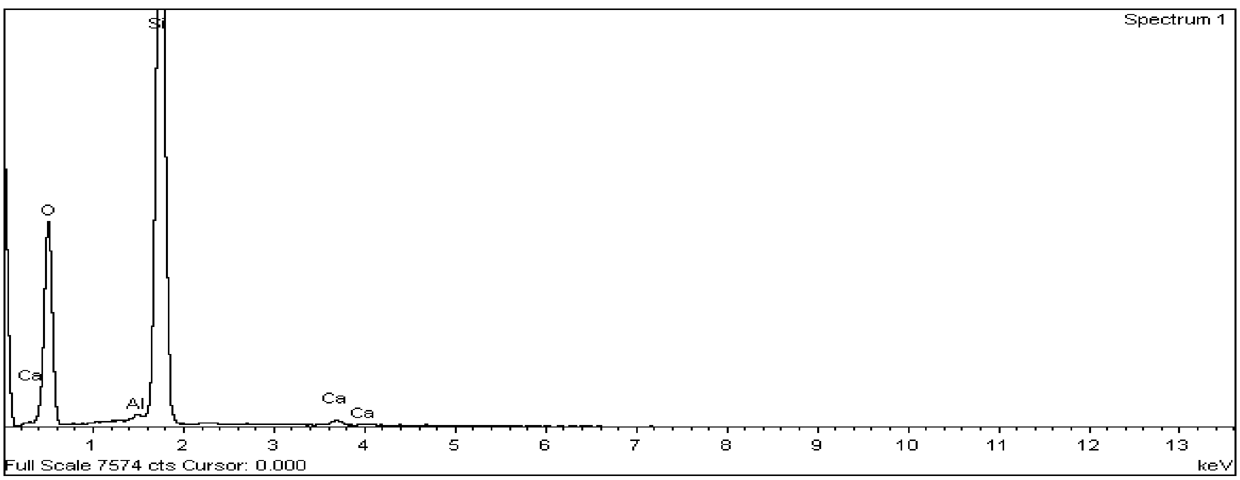


Fig 4.61 EDS Spectrum of 28 days Compressive strength test control mix sample.

Table 4.7: EDS results of the 28 days compressive strength control mix sample

Element	Weight%
O K	56.81
Al K	0.31
Si K	42.26
Ca K	0.62
Total	100

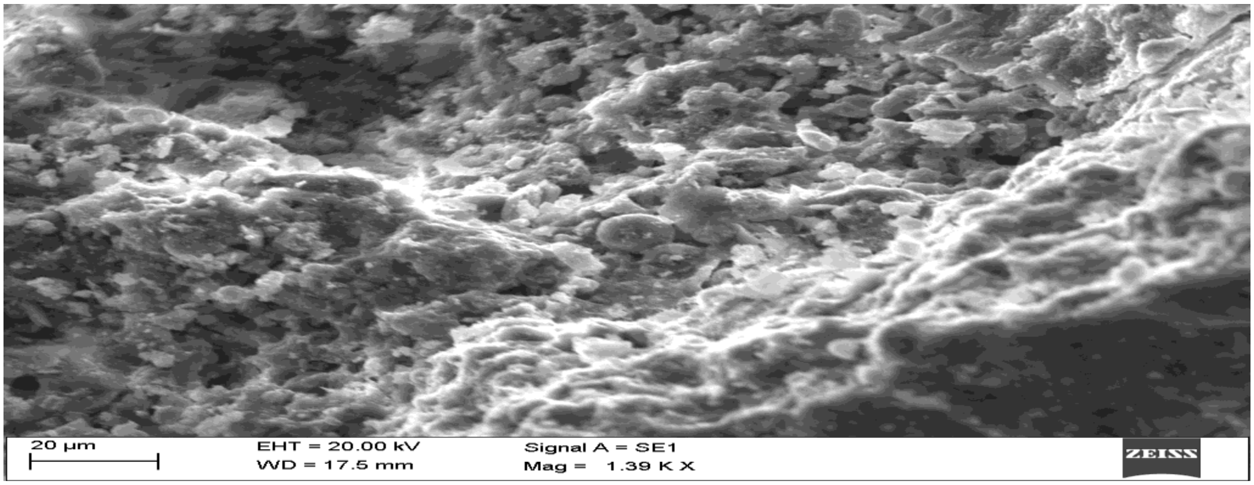


Fig 4.62 SEM image of 28 days Compressive strength test C50FA50AF10 mix sample tested at 1390X.

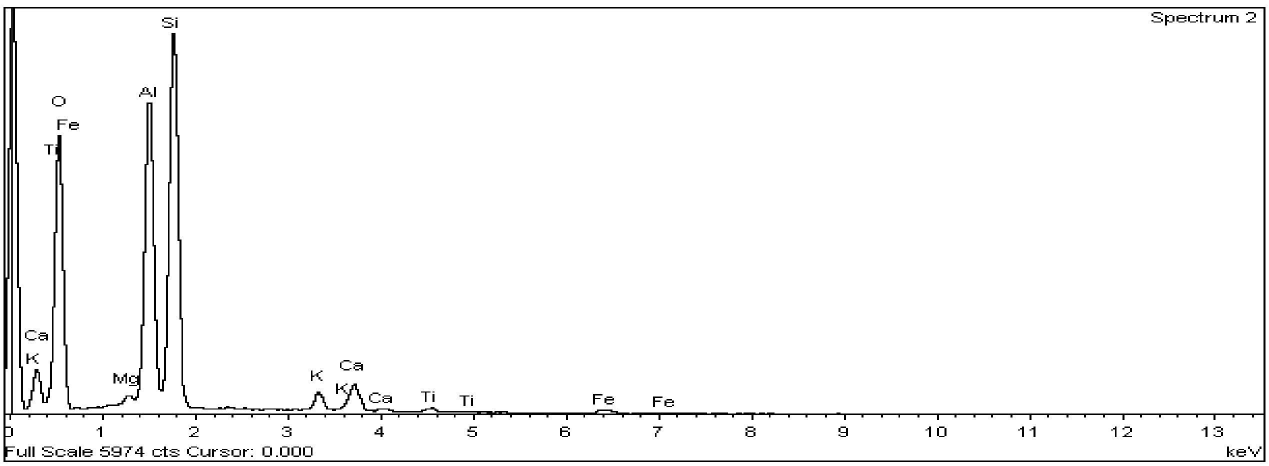


Fig 4.63 EDS Spectrum of 28 days Compressive strength test C50FA50AF10 mix sample.

Table 4.8:- EDS results of 28 days Compressive strength test C50FA50AF10 mix Sample.

Element	Weight%
O K	55.20
Mg K	0.52
Al K	15.77
Si K	23.55
K K	1.49
Ca K	2.25
Ti K	0.47
Fe K	0.75
Total	100

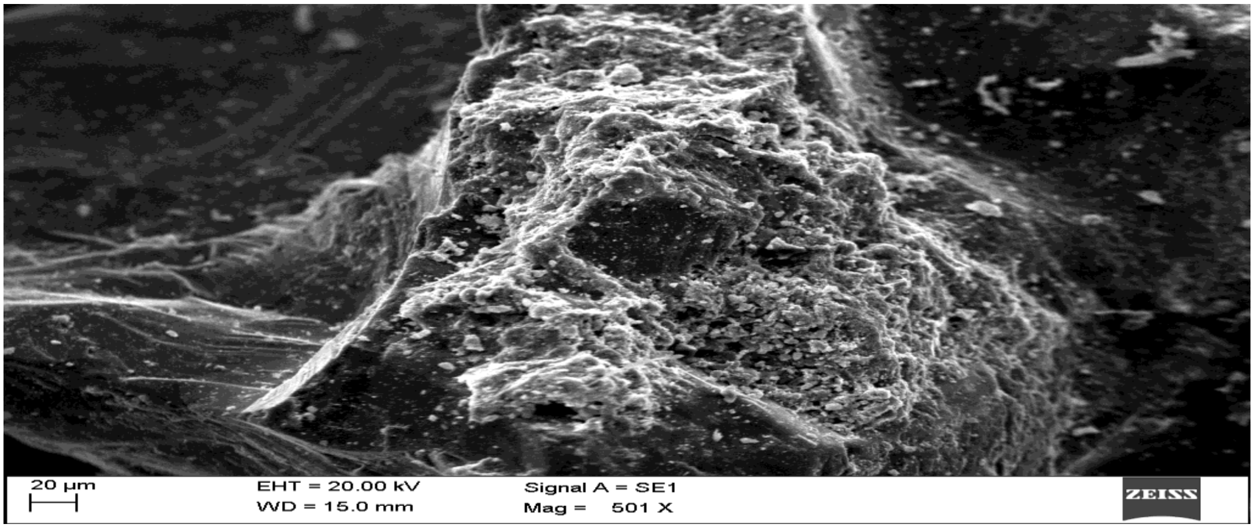


Fig 4.64 SEM image of 28 days compressive strength test C70FA30SF10 sample tested at 501X.

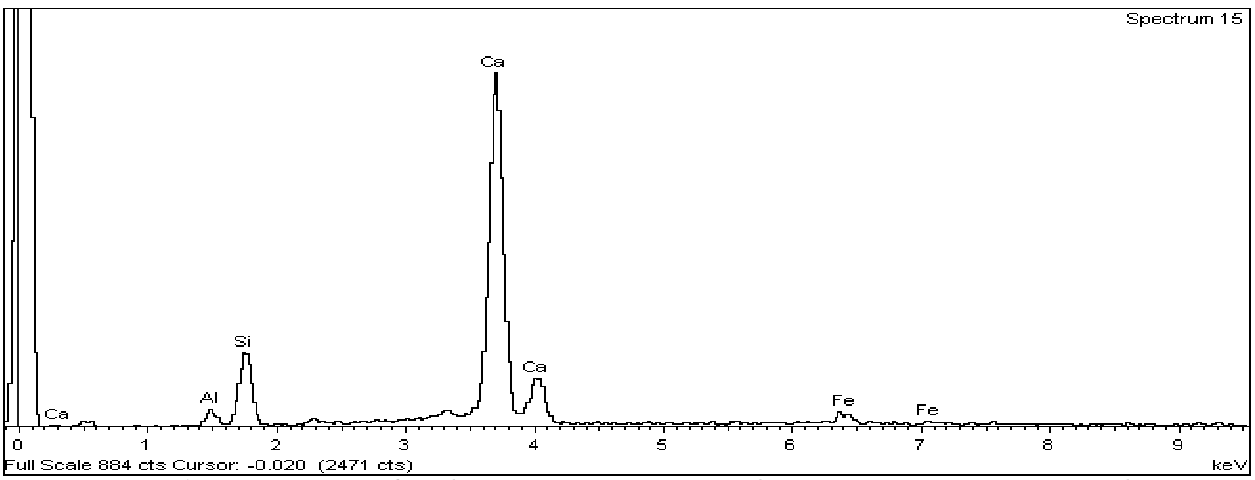


Fig 4.65 EDS Spectrum of 28 days Compressive strength test C70FA30SF10 mix sample.

Table 4.9:- EDS results of 28 days Compressive strength test C50FA50SF10 mix Sample.

Element	Weight%
Al K	2.63
Si K	11.64
Ca K	79.20
Fe K	6.53
Total	100

Discussions

From the results obtained it may be concluded that, there is substantial increase in compressive strength for the mix prepared with alcofine, which exhibited good long term strength which is almost equivalent to control mix for the percentage alccofine 10 to 15 % and flyash 30%, and shows highest values for the mix contains alccofine 10% and flyash 30%, which is 102.84% of the control mix implies the [1,6]denser formation of C-S-H gel , and [9]reduction of internal pore network. For the mix comprise of Silicafume and flyash results shows decrease in strength with percentage increase in flyash, the mix ranging Silicafume 5% to 15% and flyash 30% attribute to be better results compared to control mix , for the mix contains 10% Silicafume and 30% flyash attribute to be best which is 115.7% of the control mix, [1,6]which again signifies the formation of denser C-S H gel structure, less pore network as surface area of [4,7]Silicafume and fly ash is more compare to cement,[5] which causes more filling ability of internal voids of the mortar , which impart to reduce apparent porosity and increase in bulk density of the mortar

From scanning electron microscopy and Energy dispersive X-ray analysis of the specimen found from the fractured sample of 28 days compressive strength test, carbon coated for electrical conductivity. From Fig 4.60 to 4.64 it has been observed that there are no such notable changes observed at micro level for both the specimen e.g Control mix, C50FA50AF10, except denser formation of C-S-H gel honeycomb structure in case of C70FA30SF10 sample which probably the main reason of improvement in compressive strength for the mix, performed better than the control mix. Table 4.7 to 4.9 contains the chemical analysis of the mix and their quantity by EDS analysis.

4.8 Durability study:-

Durability of concrete may be defined as the resistance of the concrete against weathering, abrasion within the anticipated service life span. Among many other durability parameter we have studied in my course of work sample exposed to elevated temperature up to 800°C for 4 hours, sample exposed to 4 % Sulphuric acid(H_2SO_4) and magnesium sulphate ($MgSO_4$) for 56 days after 28 days normal curing.

4.8.1 Sulphuric acid exposure:-

The performance of the mix against the sulphuric acid exposure is tabulated below:-

Table : 4.10

Performance of the mix in acid exposure

Sl No	Name of the Mix	weight loss/Gain in %	Strength Before H_2SO_4 in MPa	Strength After H_2SO_4 in MPa	Residual strength in %
1	C100	-5.59	46.7	21.06	45.1
2	C70FA30AF5	-8.97	39.2	21.33	54.5
3	C70FA30AF10	+3.5	45.06	15.73	35
4	C70FA30AF15	+3.65	44	23.2	52.73
5	C50FA50AF5	-1.542	36	13.06	36.28
6	C50FA50AF10	-6.82	48	9.33	19.44
7	C50FA50AF15	-5.85	37.3	11.6	31.1
8	C50FA30SF5	-8.62	47.4	13.6	28.7
9	C70FA30SF10	-2.64	54	5.2	9.63
10	C70FA30SF15	3.89	40.3	15.73	39.04
11	C50FA50SF5	+5.97	36.8	16.93	45.72
12	C50FA50SF10	+4.28	34.7	20	57.64
13	C50FA50SF15	+7.24	44.3	20	45.15

Fig 4.66 Sample exposed to Sulphuric Acid of 4% Concentration

Fig 4.67 Physical condition of the Samples after 56 days Sulphuric acid exposure.

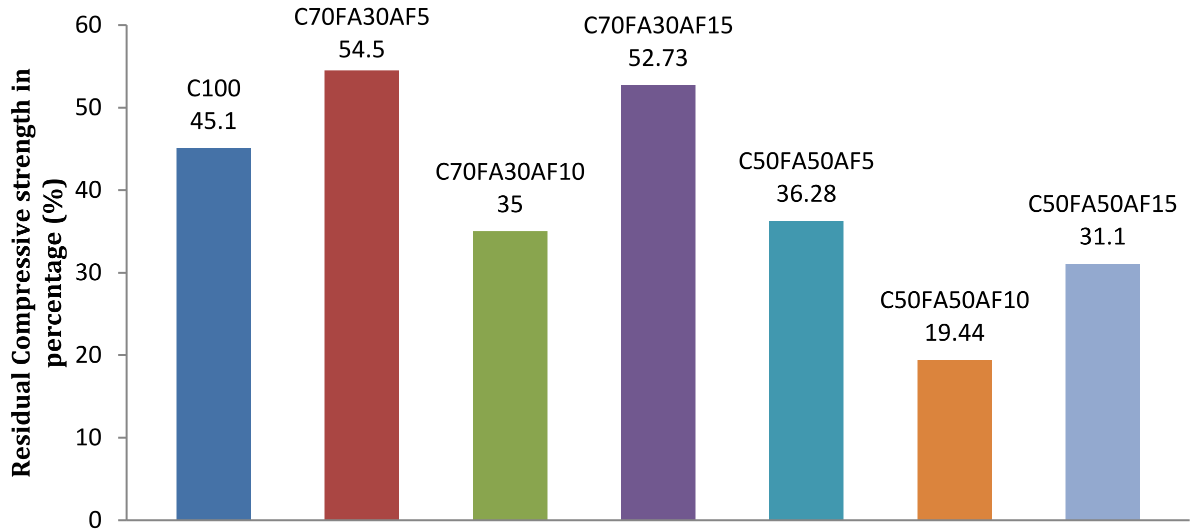


Fig 4.68:Comparision of Residual Compressive Strength Results for various % of AF and FLYASH in H_2SO_4 exposure for 56 days

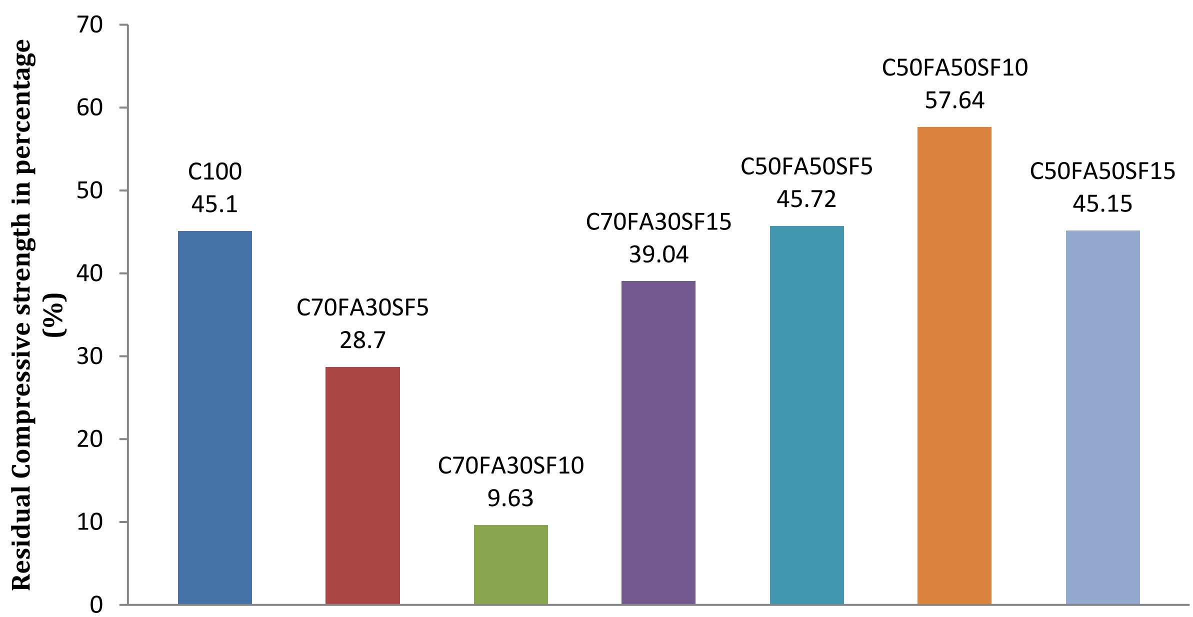


Fig 4.69:Comparision of Residual Compressive Strength Results for various % of Silicafume and FLYASH in H_2SO_4 exposure for 56 days

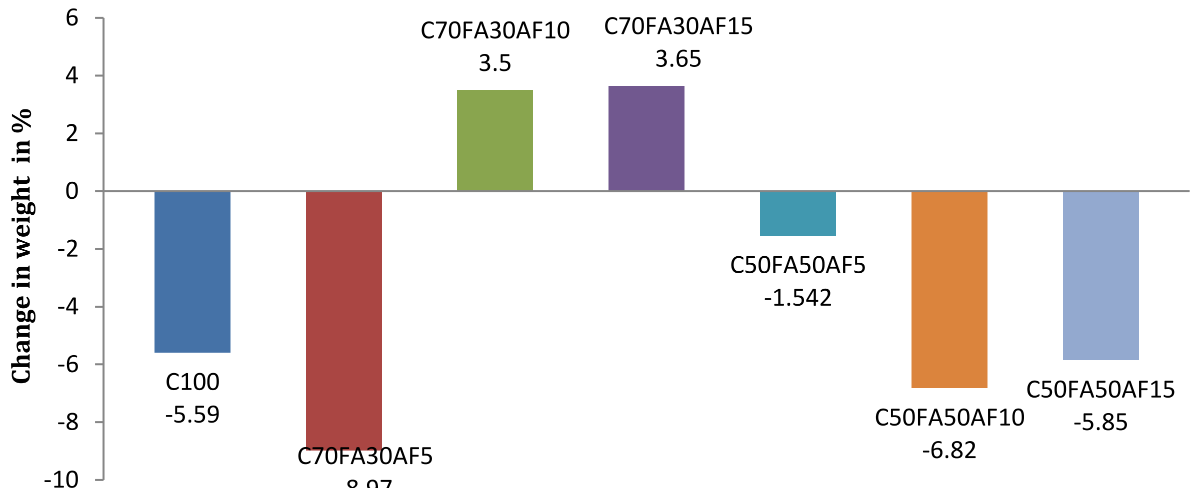


Fig 4.70:Comparision of % change in weight Results for various % of AF and FLYASH in H_2SO_4 exposure for 56 days

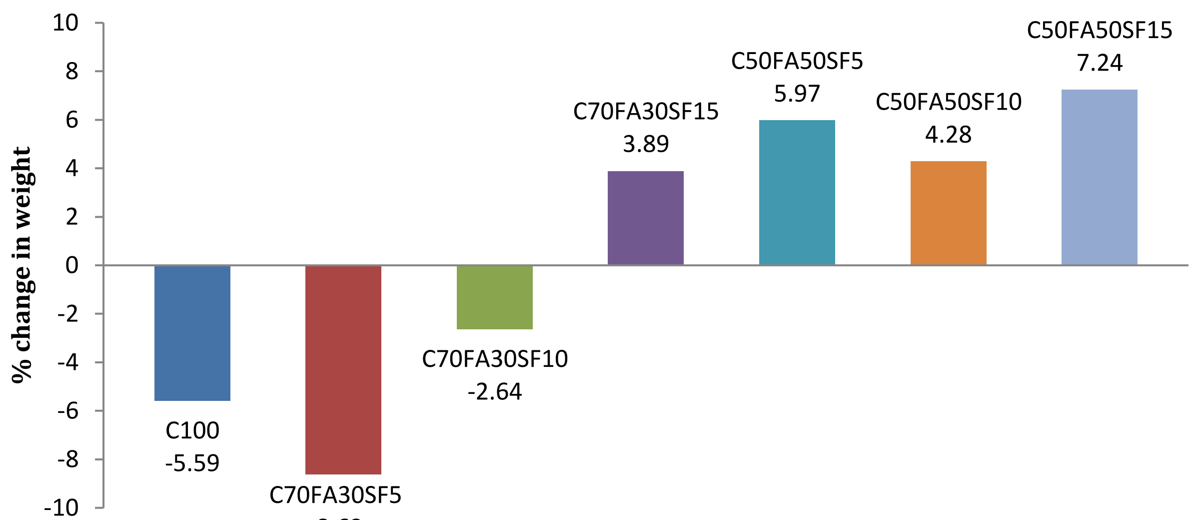


Fig 4.71:Comparision of % of change in weight Results for various % of SF and FLYASH in H_2SO_4 exposure for 56 days

Microstructure analysis Sample exposed to 4% Sulphuric acid Sol^n through SEM & EDS:-

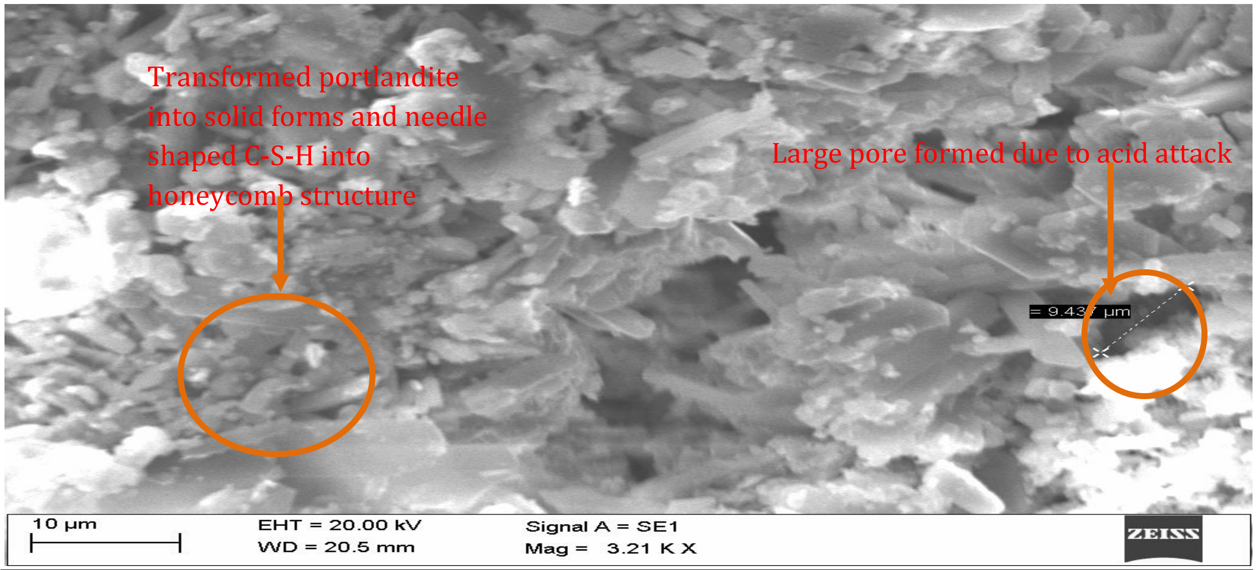


Fig 4.72 SEM image of C70FA30AF15 mix Sample exposed to Sulphuric acid tested at 3210X.

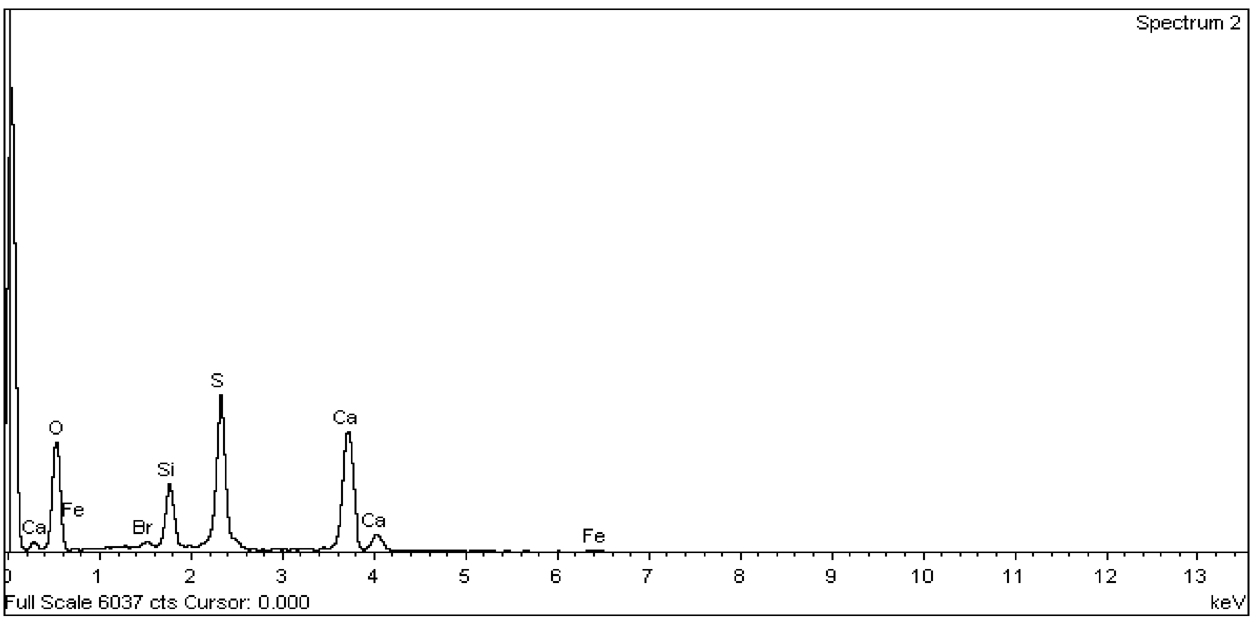


Fig 4.73 EDS Spectrum of C70FA30AF15 mix sample exposed to Sulphuric acid..

Table 4.11:- EDS results of C70FA30AF15 mix sample exposed to Sulphuric acid.

Element	Weight%
O K	59.51
Si K	5.58
S K	15.38
Ca K	17.65
Fe K	0.99
Br L	0.99
Total	100

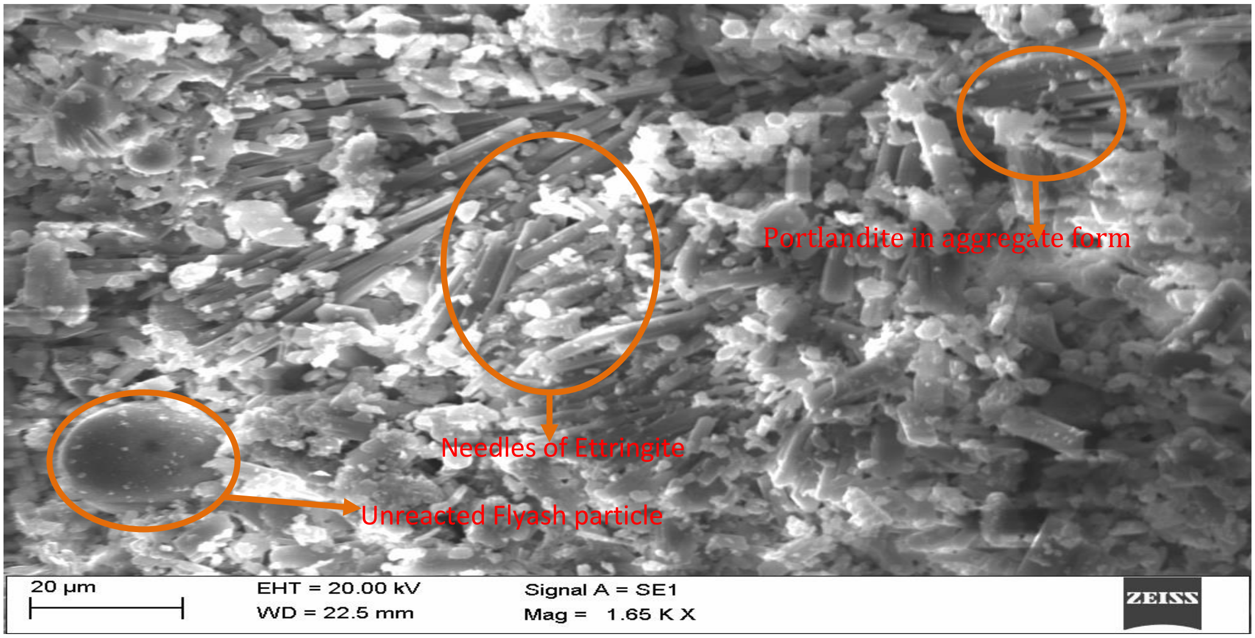


Fig 4.74 SEM image of C50FA50SF10 Surface sample exposed to Sulphuric acid tested at 1650X.

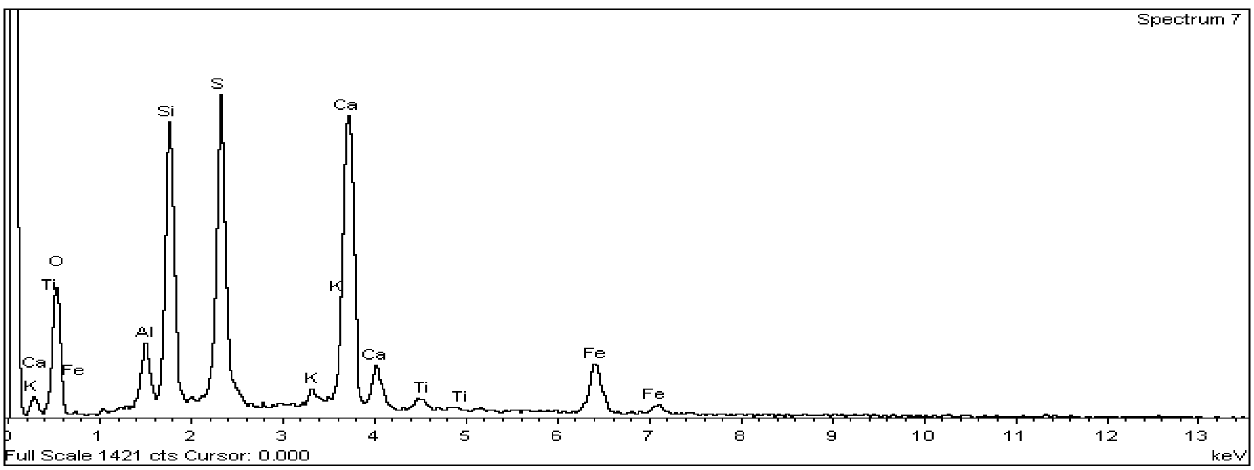


Fig 4.75 EDS Spectrum of C50FA50SF10 mix surface sample exposed to Sulphuric acid..

Table 4.12:- EDS results of C70FA30SF10 mix Surface sample exposed to Sulphuric acid.

Element	Weight%
O K	40.10
Al K	2.62
Si K	11.84
S K	15.04
K K	0.85
Ca K	20.11
Ti K	0.88
Fe K	8.57
Total	100

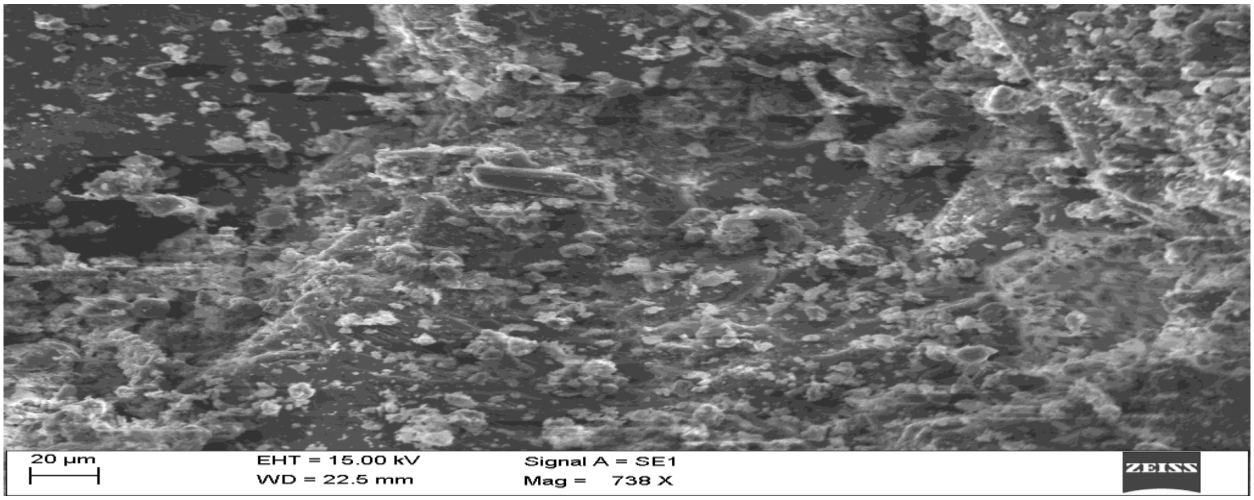


Fig 4.76 SEM image of C50FA50SF10 Core sample exposed to Sulphuric acid tested at 738X

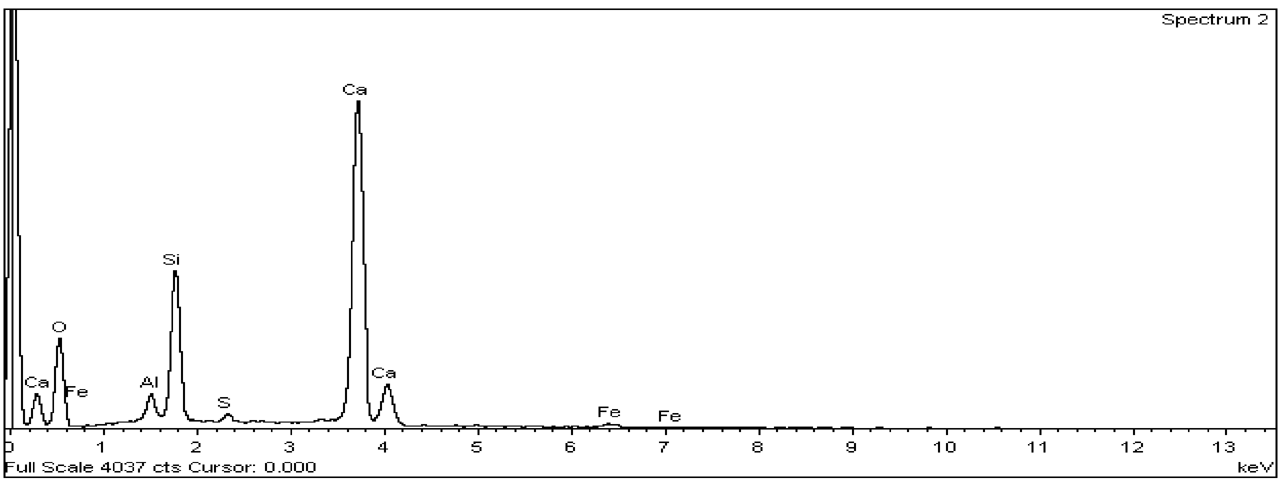


Fig 4.77 EDS Spectrum of C50FA50SF10 mix Core sample exposed to Sulphuric acid.

Table 4.13:- EDS results of C70FA30SF10 mix core sample exposed to Sulphuric acid.

Element	Weight%
O K	51.14
Al K	1.8
Si K	10.85
S K	0.72
Ca K	34.53
Fe K	0.96
Total	100

Discussion:-

From results of the sample exposed to H_2SO_4 for 56 days after 28 days normal curing , it may be attributed that for the mix consist of alccofine 5% to 15% and flyash 30% and 5% to 15% Silicafume with 50% flyash to the OPC shows less loss of strength in terms of residual strength which is approximately 17.2% and 21.75 % higher than the control mix for the specimen C70FA30AF15 and C50FA50SF10, although there is substantially better performance in terms of weight loss for the mix contains 10 to 15% alccofine and 30% flyash, which gains weight by 3.5 and 3.65% , and for Silicafume its 4.28% for the mix C50FA50SF10 [11] which indicates dense formation of hydration product.[13]Alccofine and Silicafume was much finer than OPC, It filled the micro pores in cement mortar and the ability of mortar to resist sulphuric acids attack was improved by the reduced permeability and porosity.[13,14] Decrease percentage of cement may cause reduction in portlandite (C-H) content , which may lesser the substance to react with sulphuric acid resulting less deterioration of specimen.

In this chapter we will be discussing about the changes on the specimen exposed to 4% Sulphuric acid at micro level. From fig 4.72 it has been observed that for the mix contains alccofine i.e. C70FA30AF15 transformed portlandite into solid form and honeycomb of C-S-H gel, also large pores having diameter around 9.437μm, probably due to penetration of acid, and from fig 4.74 it has been observed that the mix C50FA50SF10 having intermediate $CaSO_4$ and C_3A ratio, which justified by the presence of ettringite needle marked on the SEM image of the surface sample which causes probably the gaining of weight and also presence of un reacted flyash particle. The Core specimen of the same mix i.e. C50FA50SF10 depicted the dense formation of C-S-H gel which causes the improvement in performance of the mix in acid attack. From EDS analysis results and table 4.11 to 4.13 it may attribute to the fact that for both the specimen contains alccofine and Silicafume, Sulphate attack on Surface is more in comparison to core justified by the percentage of Sulfur present in it.

4.8.2 Sulphate exposure:-

The performance of the mix against the sulphate exposure in our study $MgSO_4$ used for the experiment purpose is tabulated below:-

Table : 4.14

Performance of the mix in Sulphate exposure

Sl No	Name of the Mix	% weight loss/gain	Strength Before $MgSO_4$ in MPa	Strength After $MgSO_4$ in MPa	Residual strength in MPa.(%)
1	C100	0.637	46.7	49.06	105.05
2	C70FA30AF5	1.123	39.2	38.4	97.44
3	C70FA30AF10	1.204	45.06	32.8	72.79
4	C70FA30AF15	0.37	44	45.73	103.93
5	C50FA50AF5	1.872	36	35.7	99.16
6	C50FA50AF10	0.655	48	35.53	74.02
7	C50FA50AF15	-0.401	37.3	43.73	117.23
8	C50FA30SF5	-0.027	47.4	45.06	95.07
9	C70FA30SF10	0.384	54	51.3	95
10	C70FA30SF15	0.37	40.3	54	133.9
11	C50FA50SF5	-0.237	36.8	43.06	117.01
12	C50FA50SF10	-0.143	34.7	41.06	118.32
13	C50FA50SF15	0.47	44.3	40.67	91.81

Fig 4.78 Sample Exposed to 4% $MgSO_4$ Solution.

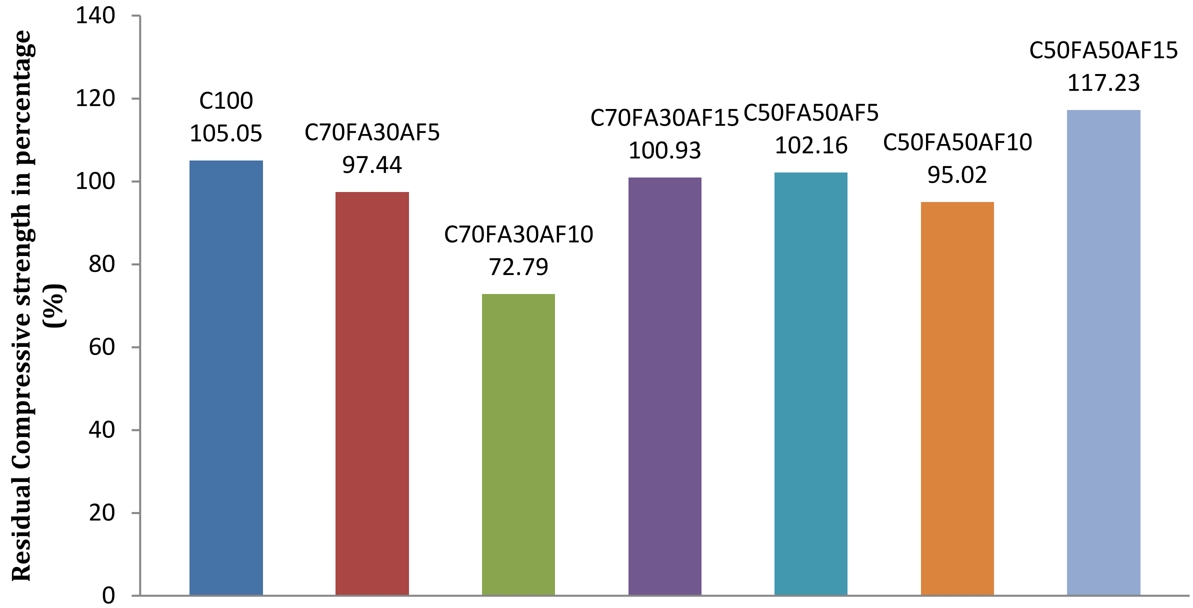


Fig 4.79:Comparision of Compressive Strength Results for various percentage of alccofine and flyash in $MgSO_4$ exposure for 56 days

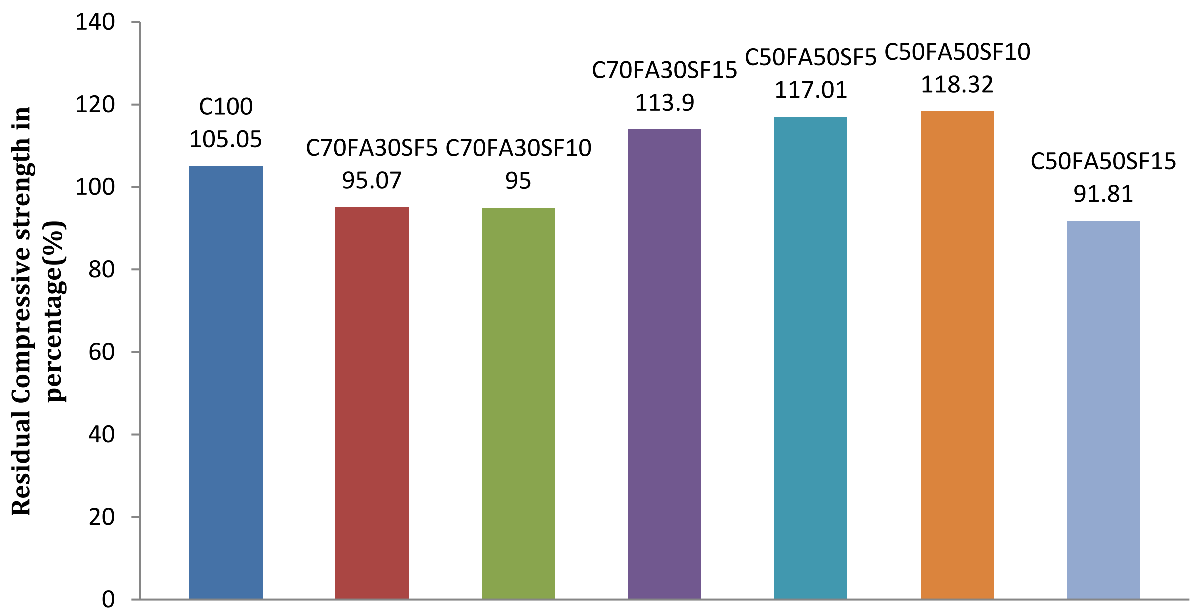


Fig 4.80:Comparision of Compressive Strength Results for various percentage of Silicafume and flyash in $MgSO_4$ exposure for 56 days

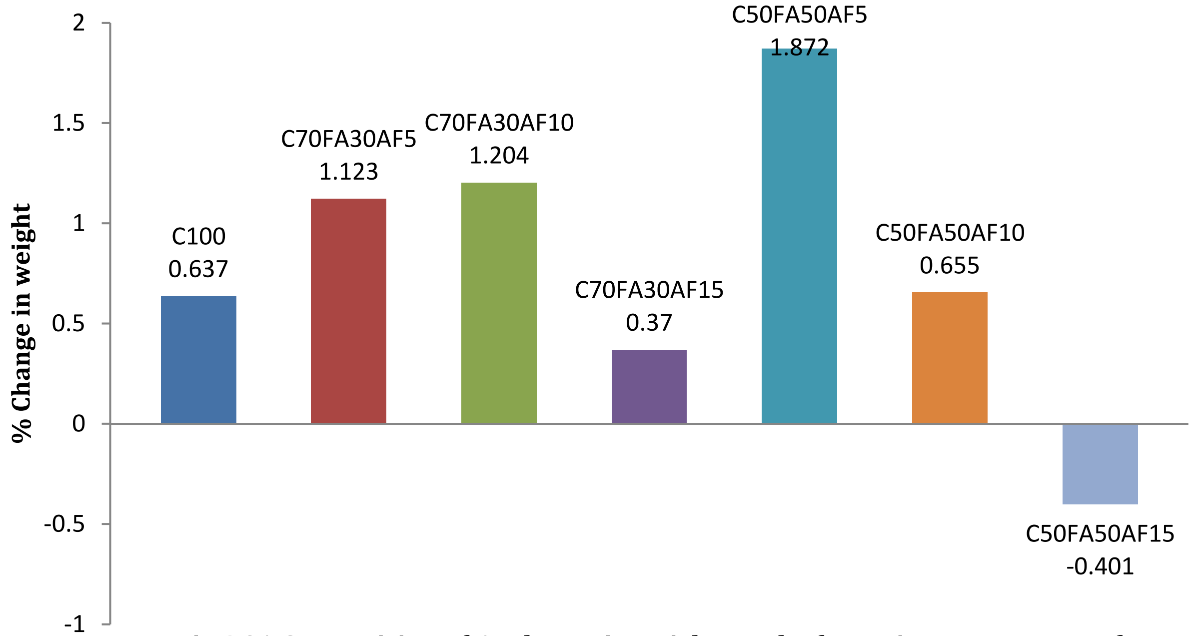


Fig 4.81:Comparision of % change in weight results for various percentage of alccofine and flyash in $MgSO_4$ exposure for 56 days

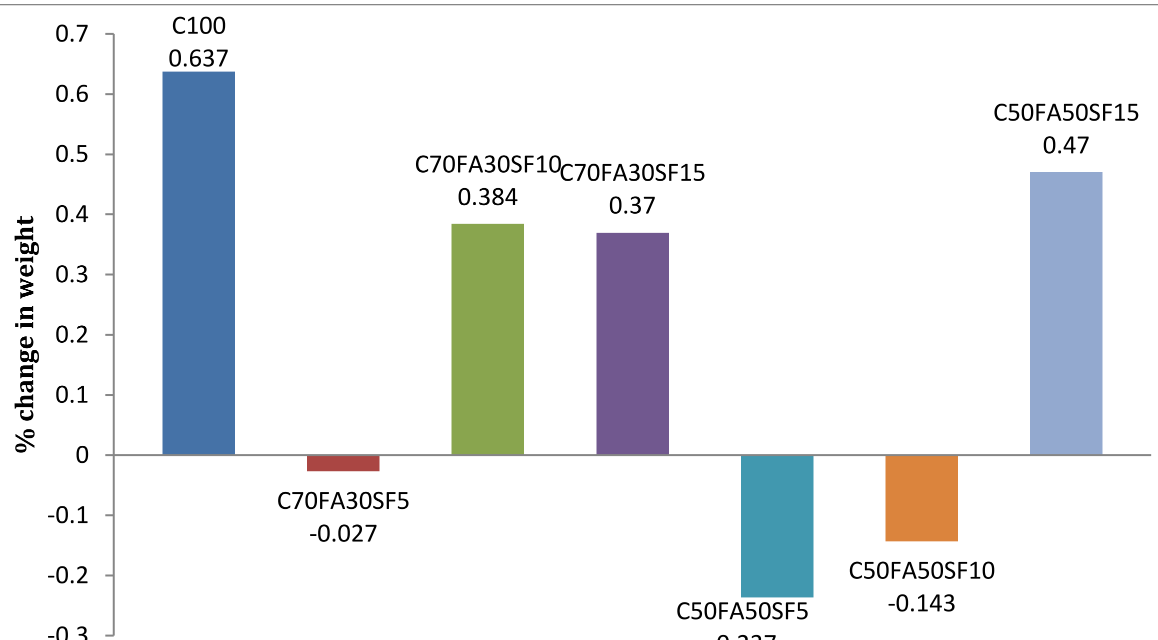


Fig 4.82:Comparision of % of change in weight Results for various percentage of SF and flyash in $MgSO_4$ exposure for 56 days

Microstructure analysis Sample exposed to 4% $MgSO_4$ solution through SEM & EDS:-

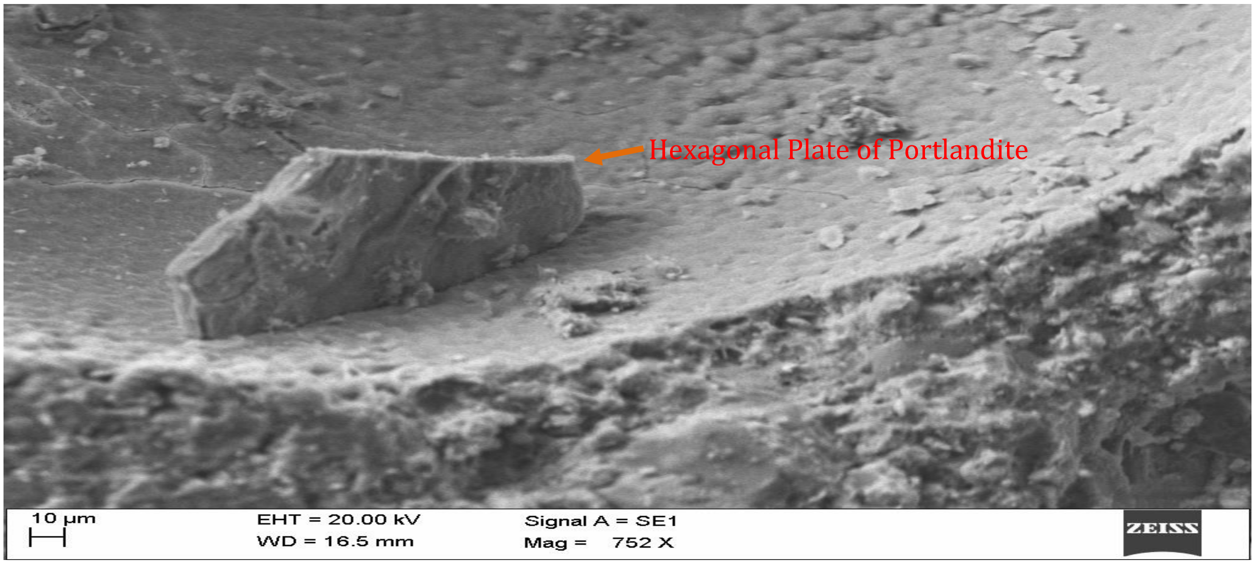


Fig 4.83 SEM image of C50FA50AF15 mix Sample exposed to $MgSO_4$ Sol^n tested at 752X.

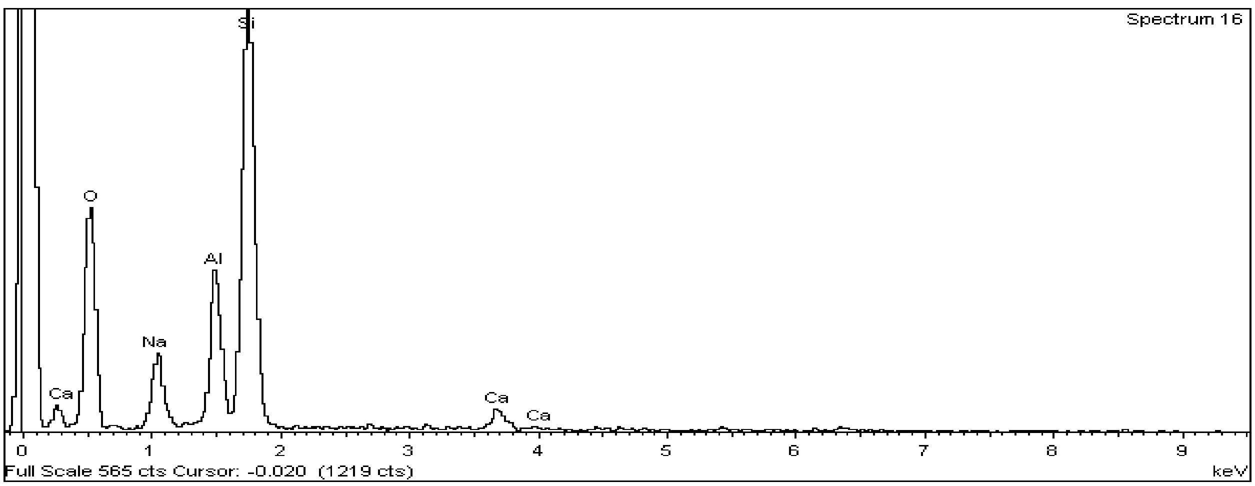


Fig 4.84 EDS Spectrum of C50FA50AF15 mix sample exposed to $MgSO_4$.

Table 4.15: EDS results of C50FA50AF15 mix sample exposed to $MgSO_4$.

Element	Weight%
O K	51.72
Na K	7.10
Al K	9.59
Si K	29.7
Ca K	1.89
Total	100

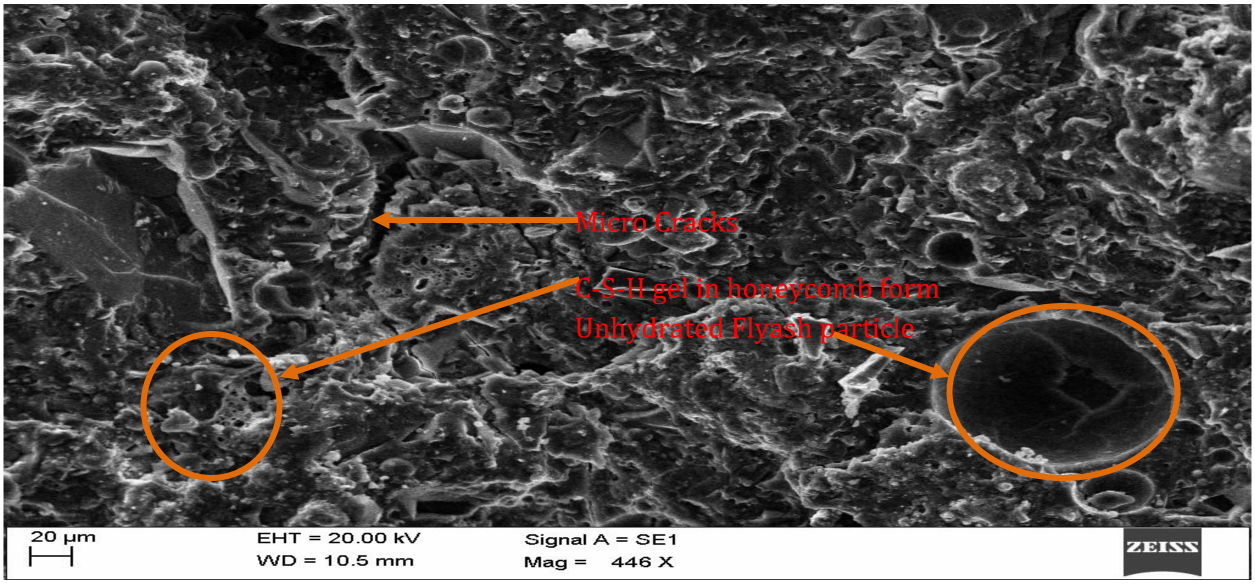


Fig 4.85 SEM image of C70FA30SF15 mix Core Sample exposed to $MgSO_4$ Sol^n tested at 446X.

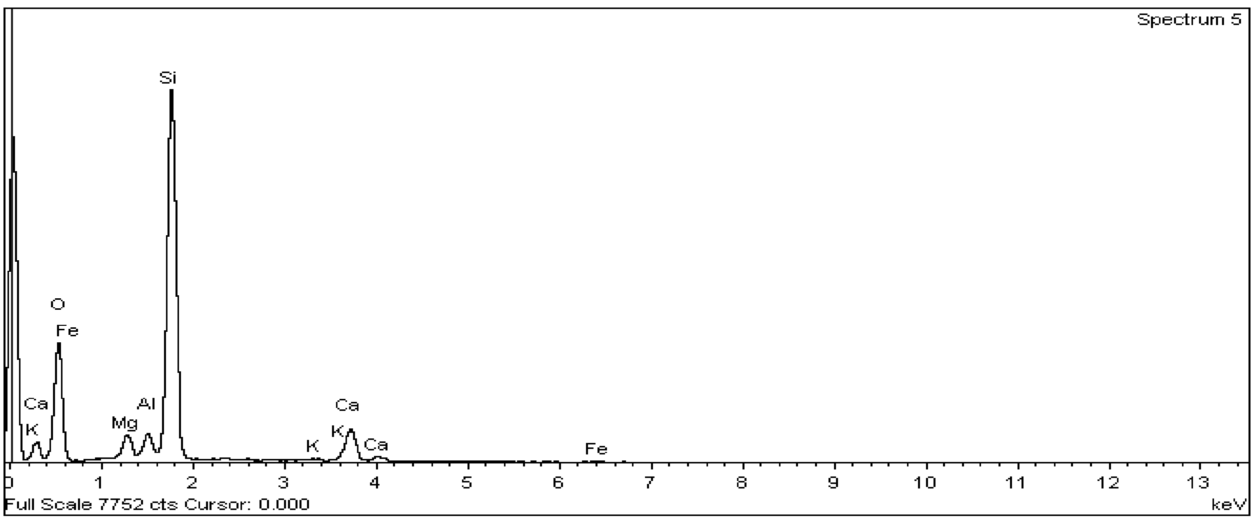


Fig 4.86 EDS Spectrum of C70FA30SF15 mix core sample exposed to $MgSO_4$.

Table 4.16:- EDS results of C50FA50SF15 mix core sample exposed to $MgSO_4$.

Element	Weight%
O K	52.07
Mg K	2.68
Al K	2.18
Si K	37.08
K K	0.31
Ca K	5.28
Fe K	0.4
Total	100

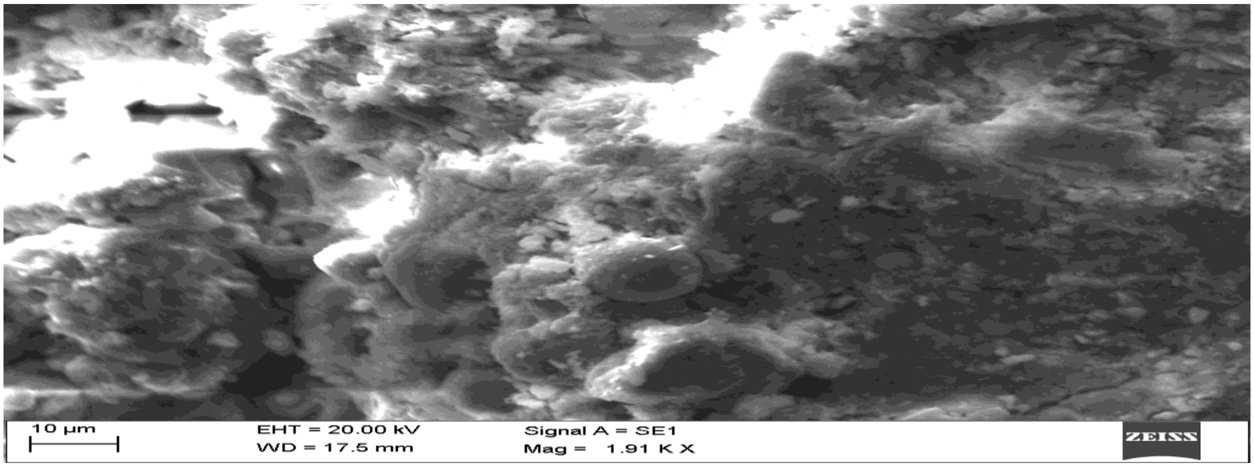


Fig 4.87 SEM image of C70FA30SF15 mix Surface Sample exposed to 4% $MgSO_4$ Sol^n tested at 1910X.

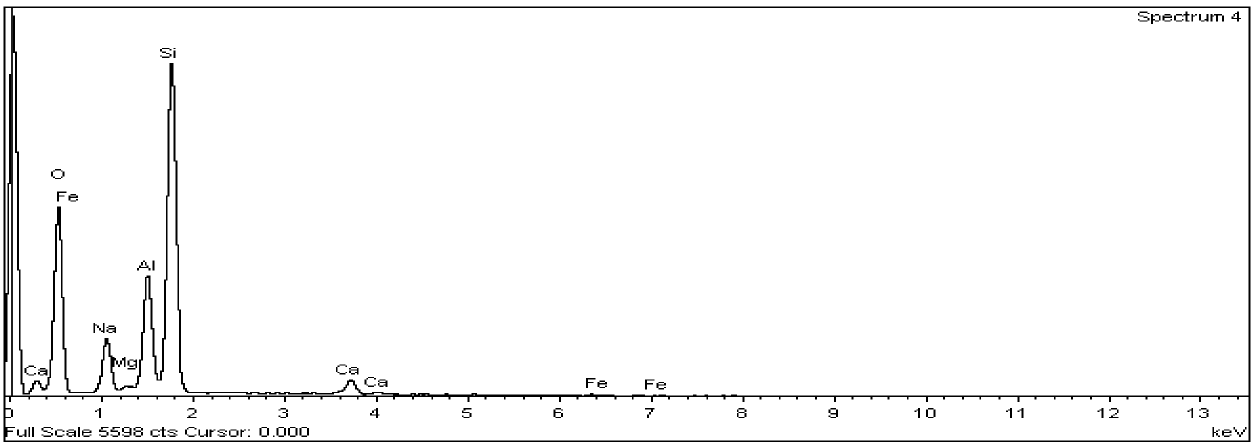


Fig 4.88 EDS Spectrum of C70FA30SF15 mix Surface sample exposed to $MgSO_4$.

Table 4.17:- EDS results of C70FA30SF15 mix surface sample exposed to $MgSO_4$

Element	Weight%
O K	52.30
Na K	6.82
Mg K	0.43
Al K	9.20
Si K	29.10
Ca K	1.77
Fe K	0.38
Total	100

Discussions:-

It has been observed from the study where sample exposed to 4% $MgSO_4$ for 56 days after 28 days normal curing, that for both the mix contains alccofine and Silicafume there is increase in strength and decrease also for certain sample, the best performing samples are lies in the range of 5% to 15% alccofine and Silicafume and 50% flyash , impart that with the increase in percentage of flyash as[1,13] flyash has long term strength gaining property due to slow rate of hydration reaction which attributed to the fact that formation of more dense C-S-H gel,[4] less pore network due to fine and ultrafine particle size of mineral admixtures than OPC. The $MgSO_4$ reacts with all cement compounds, including Calcium Silicate Hydrates [C-S-H] and subsequently forming Gypsum and Ettringite .[14] Again Magnesium hydroxide reacting with C-S-H gel formed M-S-H gel which affects the durability and loss of strength and weight of the sample. [14]Maximum sample exposed to $MgSO_4$gaining weight, which may be the cause of formation of byproduct ettringite by reacting C_3A with gypsum,[15] also deterioration of specimen in sulphte attack is more susceptible in low temperature rather than normal temperature.

From the micro structural analysis of the specimen exposed to 4% $MgSO_4$ solution it has been observed that specimen exposed to sulphate solution contributes to improvement in strength partially with the weight gain which may be due to the production of expansive product formation like ettringite into the paste, although its presence not evident from the SEM images. Also it may be concluded that there is not much changes observed for both the mix at micro level except denser formation of C-S-H gel matrix causing increase in strength, also lack of pore spaces it is justified the fact that both the mix improves performance in Sulphate attack.

4.8.3 Thermal exposure:-

The performance of the mix against the thermal exposure in 800°C elevated temperature for 4 hours our study is tabulated below:-

Table : 4.18

Performance of the mix in thermal exposure

Sl No	Name of the Mix	% weight loss/gain	28 days compressive strength MPa.	Residual Strength after thermal exposure in MPa.	Residual strength in %
1	C100	-8.25	46.7	8.3	17.77
2	C70FA30AF5	-14.3	39.2	11.2	28.57
3	C70FA30AF10	-10.4	45.06	11.73	26.01
4	C70FA30AF15	-9.75	44	12.2	27.72
5	C50FA50AF5	-11.88	36	7.2	20
6	C50FA50AF10	-10.49	48	9.33	19.4
7	C50FA50AF15	-10.03	37.3	8	21.39
8	C50FA30SF5	-9.88	47.4	9.06	19.11
9	C70FA30SF10	-10.7	54	13.3	24.68
10	C70FA30SF15	-10.66	40.3	11.7	29.03
11	C50FA50SF5	-9.49	36.8	8.93	24.2
12	C50FA50SF10	-11.1	34.7	10.4	29.9
13	C50FA50SF15	-11.2	44.3	10	22.57

Fig 4.89 Sample exposed to elevated temperature up to 800°C

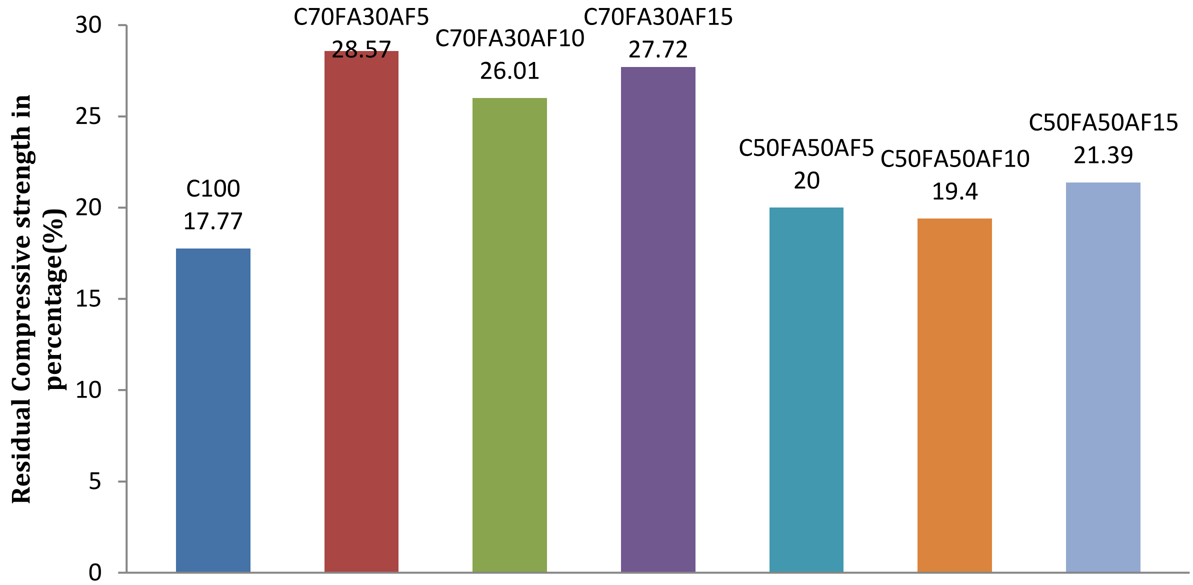


Fig 4.90:Comparision of Compressive Strength Results for various percentage of AF and FLYASH in Thermal exposure under 800°C elevated temparature for 4 hours

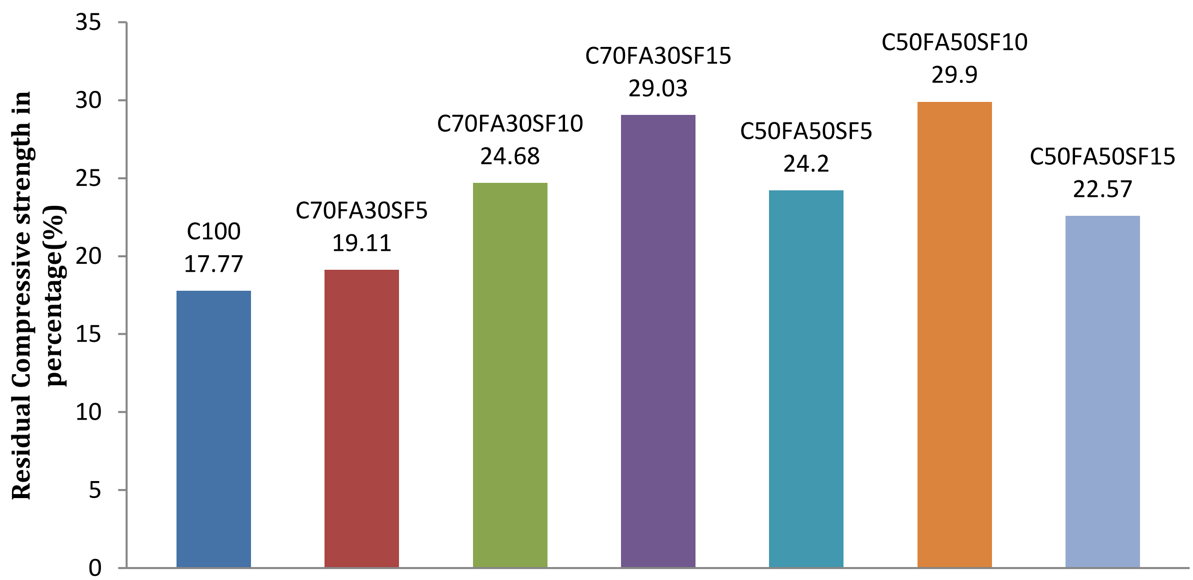


Fig 4.91:Comparision of Compressive Strength Results for various percentage of SF and FLYASH in Thermal exposure under 800°C elevated temparature for 4 hours.

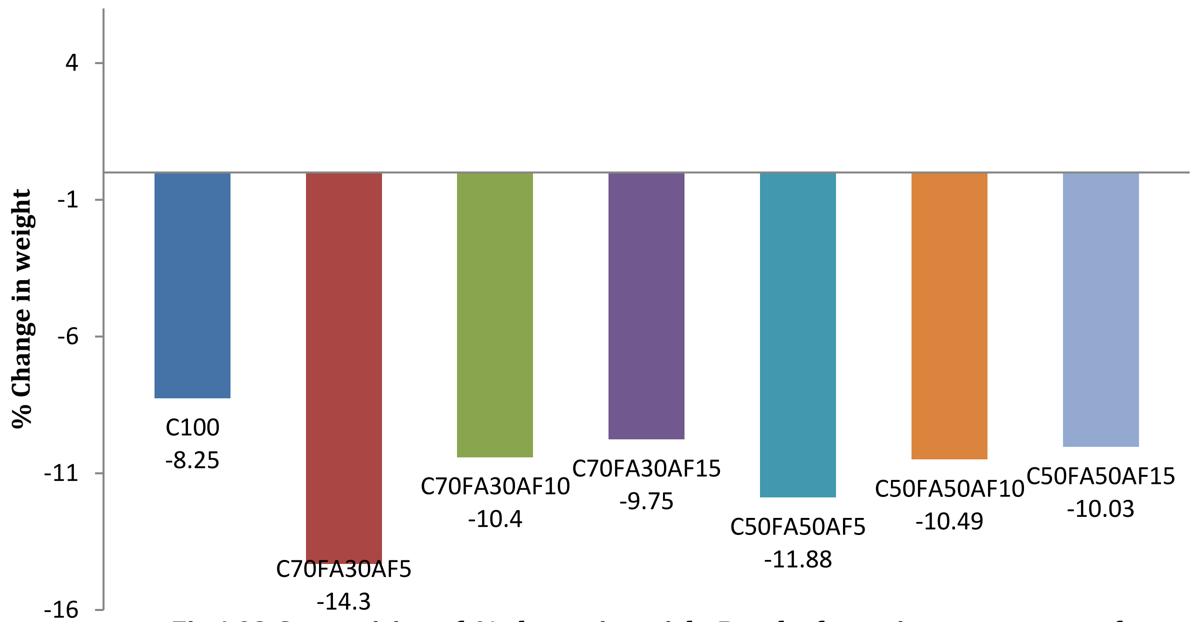


Fig 4.92:Comparision of % change in weight Results for various percentage of AF and FLYASH in Thermal exposure under 800C for 4 hours

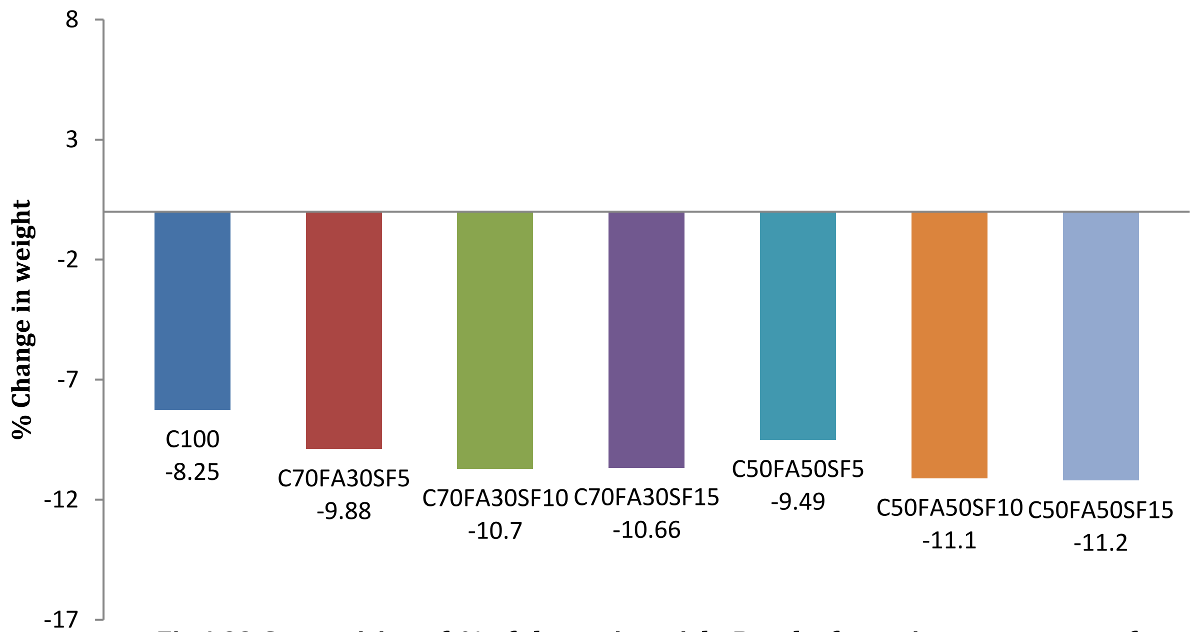


Fig 4.93:Comparision of % of change in weight Results for various percentage of SF and FLYASH in Thermal exposure under 800°C for 4 hours

Discussion:-

From the results obtained, it may be concluded that specimen composed of alccofine and Silicafume showed samples of the performing in terms of residual strength for the mix contains 5% to 15% alccofine and Silicafume and 30 % flyash compared to the control mix, which is up to 10.8 % for alccofine mix and 11.26 % higher for Silicafume mix than the control mix. Although in terms of weight loss the entire sample not performed well in comparison to the control sample.

CHAPTER V CONCLUSIONS

5.1 GENERAL

Ordinary Portland cement was replaced with various mineral admixtures like Flyash, Alccofine and Silicafume used as Supplementary Cementitious materials and additives as well. Processed flyash supplied by a Company has been used in our entire course of thesis work. Mortar prepared with Supplementary Cementitious materials and additives with varying percentages, exposed to acidic, Sulphate and thermal exposure conditions to study their durable performances also their fresh and hardened property had been studied. Thereby following conclusions may be drawn from the experimental results obtained.

(1) There is substantial improvement in workability with the inclusions of alccofine, , Silicafume do not contribute much in improving the workability of the mix.

(2) We have observed the reduction in water absorption with inclusions of alccofine, Silicafume and flyash up to certain percentages, which highlights the effects of SCM's, especially its function in the reduction of pore spaces and densification of C-S-H gel matrix.

(3) We have observed that there is not much contribution in improving initial Sorptivity of both the mixes contains Alccofine and Silicafume, but there is Substantial improvement in secondary sorptivity of the mix contains alccofine in the range of 5 to 15% with 30% replacement level of flyash.

(4) From the results of 7 days Compressive strength results, it may be concluded that both the mixes has slow rate of hydration reaction property, gaining of less short term strength has been observed compared to the control mix and performed best up to 30% replacement of flyash.

(5) It may be concluded from the results of 28 days compressive strength that not much improvement in compressive strength has been observed with the inclusions of alccofine, for Silicafume it increases substantially up to 15% than control mix for a replacement level of 10% Silicafume and 30% flyash combinations, which attributed

to the fact of lessening of pore network and internal voids as surface area of flyash and Silicafume is higher than the ordinary Portland cement.

(6) Both the specimen exposed to Sulphuric acid for 56 days after normal water 28 days curing shows better performances than the control mix in terms of residual strength and weight loss.

From the topographical study at microstructural level it's evident that there is formation of internal hydration product like ettringite in the best performing mix of the Silicafume series which causes gain in weight, transformation of portlandite into a secondary C-S-H gel which improves performance of the mixes subjected to acid exposure. Also changes in chemical compositions of the mix exposed to acid compared to 28 days normal cured mix was also observed.

(7) In the case of sulphate exposure it has been observed that with the increase in flyash percentages there is an improvement in the performance of the mix .Also for inclusions of both alccofine and silica fume, there is an increase in sulphate resistivity of the concerned concrete mix.

At the micro structural level not much difference in gel structure with respect to the formation of inner hydration product observed for the particular test sample except changes in chemical compositions obtained from EDS analysis.

(8) For samples exposed to elevated temperature, it has been observed that with the inclusions of additives there is no improvement in terms of residual strength and weight loss compared to control mix.

5.2 Limitations of study:-

(1)Due to the limited time period of the study, this thesis work confined itself to study the performance of the sustainable concrete specimens prepared with particular replacement of flyash as supplementary cementitious materials up to 50%.

(2) Acid and Sulphate exposure has been studied for 56 days but in practice behavior or performance of the mix should be studied for a longer duration of time.

(3) Due to limitations of time and laboratory setup we have confined our self to study the performance of the mix in elevated temperature for 4 hours duration only up to 800°C. But in practice fire exposure may continue beyond 4 hours in such situations behavior of mortar may vary substantially.

5.3 Future scope of work:-

(1) For preparation of sustainable concrete produced with purely supplementary cementitious materials and additives i.e. 100% replacement of ordinary Portland cement may be performed and their fresh, hardened and durable property may also be investigated subsequently.

(2) Long term durability i.e. specimens exposed to acid and sulphate solutions for minimum 1 year or more may be performed.

(3) We have tested the sample for a specific concentration of acid and sulphate concentration i.e. 4%, whereas investigation should be performed for higher concentrations also.

(4) The entire series of experiment was performed for a specified water cement ratio i.e. 0.36 in this case, but with varying water cement ratio performance of the mix may vary substantially.

(5) Performance of the mixes cured thermally should also be tested rather than subjecting the specimens to only normal water curing.

(6) Test may be performed to study the alkali silica reaction of the sustainable concrete specimens.

ANNEXURE-I

Mix Proportions

(Applicable to all types of mix)

(a) Cementitious materials:- 1

(b) Sand:- 2.628

(c) Water/Cement:- 0.36

(d) Admixture:- Super plasticizer(Master Glenium)

Sample calculations for the mix C100

(Control mix with 100% OPC)

Cement Grade: - OPC43

No of Sample: - 15 no's

Cement: - 1250 gm

Sand/Cement: - 2.628

Sand:- 2.628x1250= 3285 gm

Water/Cement: - 0.36

Water: - 0.36x1250= 450 ml

Admixtures: - 1% by weight of cementitious material= 0.01x1250=12.5 gm

Mix proportion Summary for 15 no's of 50x50 mm cube casting

OPC 43= 1250 gm

Sand=3285 gm

Water=450 ml

Admixture (Super Plasticizer) =12.5 gm

Water/cement: - 0.36

Sample calculations for the mix C70FA30AF15/C70FA30SF15

(For 70% cement, 30% Flyash and 15% alccofine or Silicafume)

Cement Grade: - OPC43

No of Sample=15 no's

Alccofine or Silicafume=15% of Cementitious material= 0.15x1250=187.5 gm

Cement= 0.7x (1250-187.5) = 743.75 gm

Flyash= 1250-743.75-187.5=318.75 gm

Sand/Cementitious material: - 2.628

Sand:- 2.628x1250= 3285 gm

Water/Cement: - 0.36

Water: - 0.36x1250= 450 ml

Admixtures: - 1% by weight of cementitious material= 0.01x1250=12.5 gm

Mix proportion Summary for 15 no's of 50x50 mm cube casting

OPC 43= 743.75 gm

Flyash= 318.75 gm

Alccofine/ Silicafume= 187.5 gm

Sand=3285 gm

Water=450 ml

Admixture (Super Plasticizer) =12.5 gm

Water/cement: - 0.36

TABLE: A.1.1:MIX PREPARATION USING ALCCOFINE

Mix	Cement		FLYASH		Alccofine		Sand (gm)	Water (ml)	W/B	Remarks
	%	gm	%	gm	%	gm				
C100	100	1250	0	0	0	0	3285.00	450	0.36	for 15 nos cubes
C70FA30AF5	70	831.25	30	356.25	5	62.5	3285.00	450	0.36	do
C70FA30AF10	70	787.5	30	337.5	10	125.00	3285.00	450	0.36	do
C70FA30AF15	70	743.75	30	318.75	15	187.50	3285.00	450	0.36	do
C50FA50AF5	50	593.75	50	593.75	5	62.50	3285.00	450	0.36	do
C50FA50AF10	50	562.50	50	562.50	10	125.00	3285.00	450	0.36	do
C50FA50AF15	50	531.25	50	531.25	15	187.50	3285.00	450	0.36	do

TABLE:A.1.2.MIX PREPARATION USING SILICAFUME

Mix	Cement		FLYASH		Silicafume		Sand (gm)	Water (ml)	W/B	Remarks
	%	gm	%	gm	%	gm				
C100	100	1250	0	0	0	0	3285.00	450	0.36	for 15 nos cubes
C50FA30SF5	70	831.25	30	356.25	5	62.5	3285.00	450	0.36	do
C70FA30SF10	70	787.5	30	337.5	10	125.00	3285.00	450	0.36	do
C70FA30SF15	70	743.75	30	318.75	15	187.50	3285.00	450	0.36	do
C50FA50SF5	50	593.75	50	593.75	5	62.50	3285.00	450	0.36	do
C50FA50SF10	50	562.50	50	562.50	10	125.00	3285.00	450	0.36	do
C50FA50SF15	50	531.25	50	531.25	15	187.50	3285.00	450	0.36	do

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