IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Investigation Into The Strength And Durability Of Concrete Enhanced With Mineral Admixtures

P.R. SARANYA[1], A. NALLAMUTHU[2]
1 ASSISTANT PROFESSOR, 2 PG STUDENT
CONSTRUCTION ENGINEERING AND MANAGEMENT
SURYA GROUP OF INSTITUTIONS, TAMILNADU, INDIA

ABSTRACT

This study explores the impact of mineral admixtures, such as fly ash, silica fume, and metakaolin, on the strength and durability of concrete. The primary focus is on M40 grade concrete, with fly ash replacing a portion of the cement according to IS10262:2009 standards. The replacement levels considered are 0%, 5%, 10%, 15%, and 20% for both silica fume and metakaolin. The investigation involves a comprehensive analysis of compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days, along with various durability tests. According to the test results, the incorporation of both silica fume and metakaolin has demonstrated an enhancement in the concrete's strength at specific replacement percentages.

KEYWORDS: Comprehensive, flexural strength and atmosphere.

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1. INTRODUCTION

Concrete is a widely used construction material for various types of structures due to its structural stability and strength. The usage, behaviour as well as the durability of concrete structures, built during the last first half of the century with Ordinary Portland Cement (OPC) and plain round bars of mild steel, the ease of procuring the constituent materials (whatever may be their qualities) of concrete and the knowledge that almost any combination ofthe constituents leads to a mass of concrete have bred contempt. Strengthwas stressed without a thought on the durability of structures.

As a consequence of the liberties taken, the durability of concrete and concrete structures is on a southward journey; a journey that seems to have gained momentum on its path to self– destruction .The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Substantial energy and cost savings can result when industrial by products are used as a partial replacement of cement. Fly ash, Ground Granulated Blast Furnace Slag, rice husk ash, High Reactive Met kaolin, silica fume is some of the pozzolanic materials which can be used in concrete as partial replacement of cement. A number of studies are going on in India as well as abroad to study the impact of use of these pozzolanic materials as cement Fly ash, Ground Granulated Blast Furnace Slag, rice husk ash, High Reactive Metakaolin, silica fume is some of the pozzolanic materials whichcan be used in concrete as partial replacement of cement. A number of studies are going on in India as well as abroad to study the impact of use of these pozzolanic materials as cement replacements and the results are encouraging. The strength, durability and other characteristic of concrete depends on the properties of its ingredients, proportion of mix, method of compaction and other controls during placing and curing.

FLY ASH - Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases.

SILICA FUME - Silica fume is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application isas pozzolanic material for high performance concrete Silica fume is 100times finer than fly ash over 90% of silicon hydroxide. This will mean an increase rate of strength and improved impermeability at much earlier age than a fly ash mix. Silica fume was more effective than fly ash to overcome the loss of strength and produced the highest level of compressive strength atany age.

METAKAOLIN - Metakaolin is a pozzolanic material which is manufactured from selected kaolin, after refinement and calcinations under specific conditions. This heat treatment or calcinations, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder amongalumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications. Metakaolin is a fine, natural white clay which contains the highest content of siliceous, so called as High Reactivity Metakaolin (HRM).During the cement hydration process, water reacts with Portland cement and forms calcium-silicate hydrate (CSH). The by-product of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete, and hence reduces the effect of the CSH. When Metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable.

2. AIM & SCOPE

This project presents the feasibility of the usage of fly ash, silica fume and metakaolin as partially substitutes for concrete. Workability, strength and durability studies were done for concrete with fly ash and metakaolin and compared withconventional concrete.

To achieve the aim of the project, necessary and essential tests on cement, fine aggregate, coarse aggregate, fly ash, silica fume, metakaolin and concrete is carried out. These tests are required to ascertain the Vibration, in the behavior of concrete when partially replace fly ash, silica fume and metakaolin as cement.

3. LITERATURE REVIEW

IN 2013, MAGUDEASWARAN P AND ESWARAMOORTHI P HAD STUDIED THE EXPERIMENTAL INVESTIGATIONS OF MECHANICAL PROPERTIES ON MICRO SILICA (SILICA FUME) AND FLY ASH AS PARTIAL CEMENT REPLACEMENT OF HIGH PERFORMANCE CONCRETE - The Now a day, we need to look at a way to reduce the cost of building materials, particularly cement is currently so high that only rich people and governments can afford meaningful construction. Studies have been carried out to investigate the possibility of utilizing a broad range of materials as partial replacement materials for cement in the production of concrete. This study investigated the strength properties of Silica fume and fly ash concrete. This work primarily deals with the strength characteristics such as compressive, Split tensile and flexural strength. High performance concrete a set of 7 different concrete mixture were cast and tested with different cement replacement levels (0%, 2.5%, 5%, 7.5%, 10% 12.5% and15%) of Fly ash (FA) with silica fume (SF) as addition (0%,5%,10 % , 15% ,25and 30%) by wt. of Cement and/or each trial super plasticizer has been added at constant values to achieve a constant range of slump for desired work ability with a constant water-binder (w/b) ratio of 0.30.Specimens were produced and cured in a curing tank for 3, 7, 14 and 28days. Based on the experimental studies presented in this paper, the following conclusions may be drawn, the compressive strength is increased by13.9 % for the replacement of cement by 10%fly ash and 5% silica fume mix. Split tensile strength is increased by 12.15% for the replacement of cement by 15% fly ash and 7.5% silica fume mix. Flexural strength increasedby 16% for the replacement of cement by 15% fly ash and 7.5% silica fume mix.

IN 2014, ANILKUMAR P, M RAGHAVENDRA AND J SUDHAKUMAR HAD OF SILICA FUME AND FLY ASH ON DURABILITY CHARACTERISTICS OF HIGH-CONCRETE - It is evident that mechanical and durability characteristics of high-performance concrete are complex and several standard tests are available to access the above-mentioned parameters. The tests that were carried outinclude water absorption, abrasion resistance, sulphate attack and permeability. This paper discusses the experimental evaluation of durability characteristics of high-performance concrete made from mixes using various percentages of fly ash and silica fume. Durability characteristics such as water absorption, permeability, sulphate attack resistance and abrasion resistance are low for the fly ash and silica fume based concrete materials as compared with conventional high-performanceconcrete. Durability characteristics of combination of different percentage of pozzolanic material with partial replacement of cement in concrete can be considered as a scope for further studies.

IN 2004, PERUMAL K AND SUNDARARAJAN R HAD INVESTIGATED THE EFFECT OF PARTIAL REPLACEMENT OF CEMENT WITH SILICA FUME ON THE STRENGTH AND DURABILITY CHARACTERISTICS OF HIGH-PERFORMANCE CONCRETE - Maintenance, repair and rehabilitation of existing cement concrete structures involve a lot of problem leading to significant expenditure. In the recent past, there has been considerable attention or improving the propertiesof concrete with respect to strength and durability, especially in aggressive environments. High performance concrete (HPC) appears to be better choice for a strong and durable structure. Suitable addition of mineral admixtures such as silica fume (SF), ground granulated blast furnace slag and fly ash in concrete improves the strength and durability of concrete due to considerableimprovement in the microstructure of concrete composites, especially at the transition zone Very few studies have been reported in India on the use of SFfor development of HPC and also durability characteristics of these mixes have not been reported. This paper reports on the performance of HPC trial mixes having different replacement levels of cement with SF. The strength and durability characteristics of these mixes are compared with the mixes without SF. Compressive strengths of 60 MPa, 70 MPa and 110 MPa at 28days were obtained by using 10 percent replacement of cement with SF. The results also show that the SF concretes possess superior durability properties Even a partial replacement of cement with SF in concrete mixes would lead to considerable savings in consumption of cement and gainful utilization of SF. Therefore, it can be concluded that replacement of cement with SF up to 10 % would render the concrete stronger and more durable. This observation is in par with the maximum limit of 10 % for mineral admixture in concrete mixes as recommended by IS: 456-2000.

IN 2010, P. MUTHUPRIYA, K. SUBRAMANIAN AND B. G. VISHNURAM HAD STUDIED STRENGTH AND DURABILITY CHARACTERISTICS OF HIGH-PERFORMANCE CONCRETE - The scope of the present study is to investigate the effect of mineral admixtures such as silica fume, metakaolin and fly ash towards the performance of HPC. An effort has been made to focus on the mineral admixture towards their pozzolanic reaction, contribution towards strength properties, and durability studies. The strength characteristics such as compressive strength, tensile strength and flexural strength were investigatedto find the optimum replacement of mineral admixtures. The compressive strength of HPC with mineral admixtures at the replacement levels of 0%, 5%, 10% and 15% were studied at 3 days, 7 days, 28 days, of curing. The strengths were compared and the optimum replacement level of each mineraladmixture was arrived at. The tensile and flexural strength of HPC were obtained at the replacement levels of mineral. By adding fly ash, the 3, 7- and 28-days strength is less than that of normal concrete and strength improves atlater ages because of slow pozzolanic reaction. Admixtures at 28 days of curing. The durability studies such as permeability, acid resistance, alkalinitymeasurement and water absorption were conducted. The efficiency factorsfor silica fume and fly ash with different levels at 7 days and 28 days were obtained. From the studies conducted, it was observed that silica fume plays a vital role in improving the strength of concrete particularly at early ages. From the durability point of view, all the three mineral admixtures perform well. The presence of silica fume in the cement mixes causes considerable reduction in the volume of the large pores at all ages and thereby reducingthe permeability of the mixes.

IN 2014, SUNDARSANA RAO H, SASHINDHAR C, VAISHALI G AND VENKATA T.C HAD DESIGNED THE MIX DESIGN OF HIGH-PERFORMANCE CONCRETE USING SILICA FUME AND SUPER PLASTICIZER - High Performance Concrete (HPC) now a days used widely in the construction industry worldwide. To produce HPC with normal ingredients we use mineral admixtures like Silica fume, fly ash and metakaolin and workable agents Superplasticizers are also used. The usage of mineral admixtures in the concrete not only enhances its strength properties but also durability. The compressive strength is investigating finding the optimum use of mineral admixture (Silica fume of levels 0, 5, 10, 15, 20 and 25% at 7 days and 28 days of curing). The present investigation aims to give design mix for HPC by using silica fume and superplasticizers. The following conclusions can be made on the basis of the current experimental results. A mix design procedure for HPC using silica fume and super plasticizer is formulated by ACI method of mix design and available literature on HPC. Asthe silica fume content increases the compressive strength increases up to 15% [HPC4] and then decreases. Hence the optimum replacement is 15%. The 7 days and 28 days cube compressive strength ratio of HPC is 0.84 to 0.9The percentage replacement of cement by silica fume increases, the workability decreases.

4. MATERIALS

In the design of high performance concrete the selection of proper ingredients evaluating their properties and understanding the interaction between different materials plays a major role in performance of the concrete. The ingredients used are cement, silica fume, natural sand, manufacture sand, coarse aggregate, super plasticizer. The performancerequirements of concrete enhancements of the following

Ease of placement and compaction by no segregation.
Long term mechanical properties.
Early strength.
Toughness.
Volume stability.
Long term durability properties.
Longer service life.

The efficiency of high-performance concrete is improved by proper selection controlling and proportioning the ingredients of high-performance concrete.

5. EXPERIMENTAL PROGRAM

5.1 MECHANICAL PROPERTIES

5.1.1 COMPRESSION TEST (REF: IS: 516-1959)

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristics properties of concrete are qualitatively related to its compressive strength. Compressive strengths were attained as a result of the compressive tests conducted on the cube specimens of size 150mm x 150mm x 150mm. Cube was placed on the platform of the compression testing machine. The load was applied gradually till the concrete cubes get failed. The specimens are subjected to compressive loads in compression testing machine as per IS: 516-1969 and the crushing load is noted which gives the compressive strength of that cube. The compressive strength is the ratio of crushing load to the surface area of the specimens expressed in N/mm^2. Similarly, the compression strength values of all the cubes are found.

Compressive strength = P/A

Fig:1 Test set up for Compressive Strength Test

5.1.2 Flexure Test (Ref: IS: 516-1959)

The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol $f_{cr.}$ The flexural strengths of the respective specimens have been obtained from the flexural tests performed on the prism specimens of size 100mm x 100mm x 500mm.The flexural strength are tested using a two-point loading frame machine as per standard.

Fig: 2 Test Set Up for Flexural Strength

The modulus of rupture can be determined by using the formula $f_{cr} = (P_{max} \times l)/bh^2$. The loading must be applied centrally and without subjecting the specimen to any tensional stresses and restraints. The axis of the specimen shall be carefully aligned with the axis of the loading device. The load shall be applied without any shock and increasing continuously at specified rate.

5.1.3 Split tensile strength Test (Ref: IS: 5816-1999)

Split tensile strength of concrete is usually found by testing plain concrete cylinders. Cylinders of size 150mm x 300 mm were casting using M_{25} grade concrete. Specimens with Conventional Concrete and SCC of two different percentages were casted. During casting the conventional concrete cubes were manually compacted using tamping rods. After 24hours, the specimens were removed from the mould and subjected to water curing for 7, 14, 28 days. After curing, the specimens were tested for compressive strength as per IS: 5816-1999 using a calibrated compression testing machine of 2000KN capacity.

Two packing strips of plywood 3mm thick were provided between the specimen one at top and another at bottom. The specimen was placed on the plywood strip and aligned so that, the central horizontal axis of the specimen is exactly perpendicular to the load applying axis. The second plywood strip was placed length wise on the cylinder and the top platen was brought down till it touched the plywood. The load was applied without shock and increased continuously until the resistances of the specimen to the increasing load broke down and no greater load can be sustained.

Tensile strength of concrete $f_t = \frac{2p}{\pi d l}$

Fig :3 Test set Up for Split tensile Strength

5.1.4 ELASTIC MODULUS OF CONCRETE (Ref: IS: 516-1959)

The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region. A stiffer material will have a higher elastic modulus. Stress is the force causing the deformation divided by the area to which force is applied and strain is the ratio of the length parameter. If stress is measured in Newton, strain is a dimensionless. The Elastic Modulus for Concrete test is the most common test conducted on hardened concrete, partly because it is an easy test to perform. Concrete is not really an elastic material, i.e., it does not fully recover its original dimensions upon unloading. Hence, the elastic constants are necessarily considered for conventional design of reinforced concrete structures. The young's modulus of elasticity is a constant defined as the ratio, within the linear elastic range, of axial stress to axial strain under uniaxial loading. In the case of concrete under uniaxial compression, it has some validity in the very initial; portion of stress- strain curve, which is particularly linear, i.e., when the loading is of low intensity and of very short duration. If the loading is sustained for very long duration, inelastic creep effects come into play, even at relatively low stress levels. This test is normally conducted by using the cylinder specimens of size 150mm x 300mm. The Indian standard code IS-456 gives the following empirical formula for the elastic modulus of concrete. $\mathbf{E_c = 5000\sqrt{f_{ck}}}$. Note that the constant 5000 has the unit of $(MPa)^{1/2}$ and the equation is unit sensitive. All the test specimens cast.

Fig :4 Test set up for modulus of elasticity

5.2 DURABILITY OF CONCRETE

5.2.1 WATER ABSORPTION

The water absorption values for various mixtures of concrete were determined on 100mm x 100mm x 100mm cubes as per ASTM C 642. Concrete cube specimens were cast and kept in the aggressive medium for the period of 28 days. After 28 days specimens were taken out and placed in oven dry at the temperature of 105˚c to remove the moisture content. Then the dry weight of the specimen was measured by using electronic weighing balance and the specimens were immersed in curing tank. After 3 days of water immersion, the specimens were taken out. Dried and wet weights were recorded. Amount of water absorption were calculated with reference to dry weight of the specimen.

$$\mathbf{WA=\frac{W2-W1}{W1}x100}$$

5.2.2 SULPHATE RESISTANCE TEST

The acid resistance tests are carried out 100x100X100 mm size cube specimens at the age of 28 days curing. Then the cube specimens are allowed to dry and note the initial weight. The surface of the specimen is thoroughly prepared. Then 5% Na_2so_4 is mixed per litre of ordinary water. Cube specimens are then immersed completely in the sulphate solution for 28 days. After 28 days the cube specimen is taken out from the sulphate solution and kept dried. Then the specimens are weighed and tabulated.

5.2.3 ACID RESISTANCE TEST

The acid resistance tests are carried out 100x100 mm size cube specimens at the age of 28 days curing. Then the cube specimens are allowed to dry for 5 days and note the initial weight. The surface of the specimen is thoroughly prepared. Then 5% HCL is mixed per litre of ordinary water. Cube specimens are then immersed completely in the acid solution for 28 days. After 28 days the cube specimen is taken out from the acid solution and kept dried. Then the specimens are weighed and tabulated.

Fig:5 Specimens Immersion in Acid

5.2.4 HALF-CELL POTENTIAL TEST

Corrosion being an electro chemical phenomenon, the electrode potential of steel bars with reference to a standard electrode under goes changes depending on corrosion activity. The half-cell potential is measured by using the canin corrosion meter. To perform the half-cell potential measurements, electrical connections have to be made with the reinforcement and with the concrete surrounding it. Electrical connection with the reinforcement is simply made by connecting wire to the reinforcement and electrical connection with concrete is made by electrolyte in the $cu/cuso_4$ reference electrode which wets both the concrete surface and the conductor to which another wire can be attached.

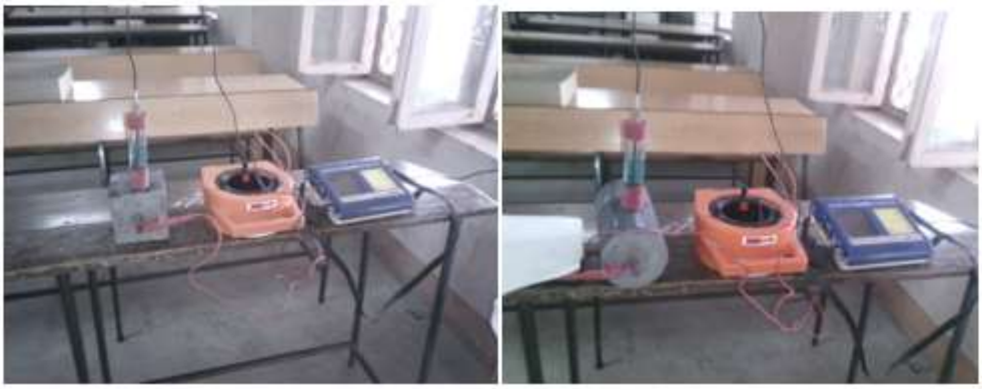

Fig :6 Test set up for half-cell potential

5.2.5 ALKALINITY MEASUREMENT

The trial mixes of cube specimens were tested for compressive strength after 28 days of water curing. The broken pieces of tested specimens were again broken into small pieces using hammer and ball mill and then powdered. Each of the powder samples (about 20 gram) was put into 100 ml of distilled water. The aqueous solution was allowed to stand for 72 hrs and more and was agitated often, to enable more of free lime of hydrated cement paste to get dissolved in water. The pH of the aqueous solution was measured by pH meter and also by putting the pieces of pH indicating papers into the solution. The color of the pH paper in the solution is matched with the standard color chart supplied by the manufacturer in order to get the pH of the solution.

6. RESULTS AND DISCUSSION

The results obtained from the various experiments conducted to access mechanical properties and durability properties of materials. The aim of the study is to determine the compressive strength, flexural strength, spilt tensile strength, modulus of elasticity, water absorption, acid resistance test, sulphate resistance test, half-cell potential test, alkalinity test, so. The results of test specimens are presented.

6.1 MECHANICAL PROPERTIES

The mechanical properties of concrete such as compressive strength, flexural strength, modulus of elasticity is determined from the standard experiments. They are as follows.

6.2.1 Compressive Strength

The compressive strength of replacement of silica fume and metakaolin is arrived. The compressive strength value for replacement of silica fume was high when compared to replacement of metakaolin.

COMPRESSIVE STRENGTH N/mm 2	REPLACEMENT PERCENTAGE				
	0 %	5 %	10 %	15 %	20 %
7 days	26.21	26.92	27.2	29.42	28.4
14 days	31.24	32.12	35.42	38.51	36.2
28 days	41.56	43.52	45.68	49.2	46.21

Fig :7 Compressive Strength of Cubes with Partial Replacement of silica fum7

COMPRESSIVE STRENGTH N/mm 2	REPLACEMENT PERCENTAGE				
	0 %	5 %	10 %	15 %	20 %
7 days	25.92	26.46	27.22	28.88	28.44
14 days	31.26	31.98	35.18	37.95	36.58
28 days	41.26	43.34	45.15	49.04	46.29

Fig :8 Compressive Strength of Cubes with Partial Replacement of metakaolin

6.2.2 FLEXURAL STRENGTH

The flexural strength of replacement of silica fume and metakaolin is arrived. The flexural strength value for replacement of silica fume was high when compared to replacement of metakaolin.

FLEXURAL STRENGTH N/mm 2	REPLACEMENT PERCENTAGE				
	0 %	5 %	10 %	15 %	20 %
7 days	1.98	2.12	2.36	2.58	2.41
14 days	2.69	2.76	3.28	3.62	3.58
28 days	3.76	3.84	4.18	4.42	4.36

Fig :9 Flexural Strength of Cubes with Partial Replacement of silica fume

FLEXURAL STRENGTH N/mm 2	REPLACEMENT PERCENTAGE				
	0 %	5 %	10 %	15 %	20 %
7 days	2.01	2.03	2.32	2.56	2.39
14 days	2.57	2.75	3.25	3.92	3.54
28 days	3.67	3.66	4.12	4.40	4.28

Fig :10 Flexural Strength of Cubes with Partial Replacement of metakaolin

6.2.3 SPLIT TENSILE STRENGTH

The variation of split tensile strength at the age of 28 days with different percentage of silica fume, metakaolin and fly ash, from the test results, it was observed that the maximum split tensile strength was obtained for mix of 15% replacement of fly ash by silica fume.

SPLIT TENSILE STRENGTH	REPLACEMENT PERCENTAGE				
	0 %	5 %	10 %	15 %	20 %
N/mm 2					
7 days	2.78	2.86	2.93	3.21	3.19
14 days	3.21	3.48	3.54	3.79	3.62
28 days	3.92	4.21	4.42	4.89	4.62

Fig :11 spilt S tensile strength of Cubes with Partial Replacement of silica fume

SPLIT TENSILE N/mm ^{2}	REPLACEMENT PERCENTAGE				
	0%	5%	10%	15%	20%
7 days	2.73	2.81	2.82	3.25	3.14
14 days	3.15	3.48	3.34	3.59	3.68
28 days	3.79	4.20	4.39	4.76	4.72

Fig :12 split tensile Strength of Cubes with Partial Replacement of metakaolin

7.CONCLUSION

In the present experimental study on concrete using fly ash, Silica fume and metakaloin specimens were tested and the following conclusions are formed from the experimental investigation.

Concrete with replacement of 15% fly ash with Silica fume and metakaloin showed good results in all mechanical properties of of silica fume

In durability study the water absorption is very low in the replacement of Silica fume in fly ash in concrete.

In acid resistance, the metakaolin replacement of 15% gives the better Results when compare with all other proportions.

In sulphate resistance test replacement of 15% metakaolin in fly ash in concrete gives the better results when compare with all other proportions.

In half cell potential test result, potential value of metakaolin replacement is very low when compare with silica fume replacement

In alkalinity measuring all value proportions are in alkaline value are more than 12.5. It shows further study on corrosion in future.

Overall the mechanical properties had good result in silica fume replacement (15%) and durability and structural test is giving the better result in replacement of metakaolin (15%).

The increase pozzolanic admixture like silica fume and metakaolin beyond the 15% a little amount of properties is decreased.

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