An Experimental Study on Strength Characteristics of Concrete by using Fly Ash and Metakaolin as Partial Replacement of Cement

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Abstract— This project presents the results of an experimental investigation carried out to find the suitability of metakaolin and fly ash in production of concrete. The conventional concrete M25 was made using OPC 53 grade and the other mixes were prepared by replacing part of OPC with metakaolin and fly ash. The replacement metakaolin levels were 5%, 10%, 15%, 20%, 25% and fly ash for all mix 5%. To evaluate optimize ratio and mechanical properties of metakaolin based concrete and compared with conventional mix. From the optimization 20% cement replacement by metakaolin superior than all the mixes.

Key words: Metakaolin, Fly ash, Compressive strength, Flexural strength, Split Tensile Strength

I. INTRODUCTION

Recent societal shift toward sustainable consumption and growth applied to civil infrastructure systems requires the construction materials to be designed and used with utmost attention to their durability and long term response. A majority of design codes and specifications use the compressive strength of concrete as the main criterion for design of concrete structures. Mechanically properties which are functions of porosity could to some extent provide indications of the transport properties of concrete, however they are not valid criteria for overall durability performances. Major transport properties of concrete are permeation, diffusion and absorption through which the aggressive media penetrate into the bulk of concrete and may cause gradual degradation. Pozzolanic materials including Fly Ash, slag, and metakaolin have been used in recent decades for developing high performance concrete with improved workability, strength and durability.

The use of supplementary cementitous materials (SCMs) is fundamental in developing low cost construction materials for use in developing countries. Concrete is the most widely used and versatile building material which is generally used to resist compressive forces. By addition of some pozzolanic materials, the various properties of concrete viz, workability, durability, strength, resistance to cracks and permeability can be improved.

Metakaolin is another pozzolanic materials which is manufactured from selected kaolins, after refinement and calcination under specific conditions. It is a highly efficient pozzolana and reacts rapidly with the excess calciumhydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicate hydrates. It is quite useful for improving concrete quality, by enhancing strength and reducing setting time, and may thus prove to be a promising material for manufacturing high performance concrete

Both the Fly Ash and Metakaolin are useful pozzolanic materials. In the present work, the results of a study carried out to investigate the effects of combination of these two materials on strength and workability of concrete are presented. The referral concrete M_{25} was made using 53 grade OPC and the other mixes were prepared by replacing part of OPC with Fly Ash and Metakaolin. The replacement levels were 5%(by weight) for Fly Ash and 0%, 5%, 10%, 15%, 20% and 25% (by weight) for Metakaolin

II. LITERATURE REVIEW

Jian Tong Ding (2002) investigated the Metakaolin on the workability, strength, shrinkage and resistance to chloride penetration of concrete were investigated and compared in this study. For the given mixture proportions, Metakaolin offers better workability than does SF. As the replay\cement level was increased, the strength of the Metakaolin – modified concrete increased at all ages. The increase in the strength was similar to that of the Fly ash – modified concrete. The incorporation of the both Metakaolin and Fly ash in concrete can reduce the free drying the free drying shrinkage and restrained shrinkage cracking width. The initial cracking appeared earlier in the Fly ash- and Metakaolin- in concrete can reduce the chloride diffusion rate significantly, with the Fly ash concrete performing somewhat better.

Nova John (2013) investigated the cement replacement levels were 5%,10%,15%,20% by weight for metakaolin. The strength of all metakaolin admixed concrete mixes over shoot the strength development of concrete. Mix with 15% metakaolin is superior to all other mixes. The increase in metakaolin content improves the compressive strength, split tensile strength and flexural strength upto 15% replacement. The result encourages the use of metakaolin, as pozzolanic material for partial cement replacement in producing high strength concrete. The inclusion of metakaolin results in faster early age strength development of concrete. The utilization of supplementary cementitious material like metakaolin concrete can compensate for environmental, technical and economic issues caused by cement production.

Shelorkar ajay (2013) observed that the compressive strength of Metakaolin based HGC increases with the increase in percentage of Metakaolin. The variations of compressive strength of HGC with different Metakaolin content of 4 %, 6 % and 8 %. As the Metakaolin increases from 4% to 8% the compressive strength increases about 9.23 MPa for 4 % Metakaolin, 12.98 MPa for 6 % Metakaolin and 20.87 MPa for 8 % Metakaolin. The increase in compressive strength due to the addition of Metakaolin is due to pozzolanic activity. The compressive strength of HGC increases by 10.13 %, 14.24 % and 22.90% due to addition of Metakaolin content of 4 %, 6 % and 8 % respectively in comparison with control concrete specimens of HGC. The variation of RCPT values in HGC for different proportions of Metakaolin blended concrete. It has been

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observed that as the percentage of Metakaolin increase the permeability of concrete decreases. Also, it was observed that values of rapid chloride permeability of HGC decrease up to 1450 coulombs, 1548.67 coulombs and 1684.70 coulombs for 4% , 6% and 8% of metakaolin respectively in comparison to control concrete specimens. The percentage reduction in permeability values in coulombs was 48.57 %, 51.88 % and 56.43% for Metakaolin content of 4%, 6% and 8% respectively.

III. MATERIALS AND THEIR PROPERTIES

A. Materials:

1) Cement:

Cement in general can be defined as a material which posses very good adhesive and cohesive properties which make it possible to bond with other material to form compact mass. As Shown in table 1

Physical properties of OPC.		**Chemical Properties of OPC**	
Properties	Chart Result	Properties	Chart Result
Fineness (Sp.Surface)	320 m^2 / Kg	% Soluble Silica	21.3
Specific gravity	3.15	% Alumina	5.2
Comp. Strength -7 days	16.25 MPa	% Iron Oxide	3.7
Comp. Strength – 28 days	25.0 MPa	% Lime	63.9
Initial setting Time	40 min	% Magnesia	0.7
Final Setting Time	230 min	% Insoluble Residue	0.9
Soundness (Le-Chatlier Exp.)*	1.0mm	% So3	2.2

Table 1

2) Fine Aggregate:

Fine aggregate are material passing through an IS sieve that is less than 4.75mm gauge beyond which they are known as coarse aggregate.Coarse aggregate from the main matrix of the concrete ,where as fine aggregate from the filler matrix between the coarse aggregate.The most important function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also helps the paste to hold the coarse aggregate particle in suspension.

Locally available river sand which is free from organic impurities is used .the sample shall be brought to an air dry condition before weighting and sieving. This may be achieved either by drying at room temperature or by heating at a temperature of 100^0c to 110^0c . the air dry sample shall be weighted and sieved successively on the appropriate sieves starting with the maximum size. Care shall be taken to ensure that the sieves are clean before use. The Physical Properties of Fine Aggregate as shown in Table 2

Property	**Value**
Specific Gravity	2.65
Fineness Modulus	3.75
Bulk Density	15.90 kN/m3
Grading	Zone-II

Table 2: The Physical Properties of Fine Aggregate

3) Coarse Aggregate:

The coarse aggregate used in this investigation should be angular in shape . The coarse aggrete should be such that passing 20mm sieve. It should uniform in shape and size . The uneven shape and sizes of coarse aggregate should not be used for investigation.

Crushed granite metal with 12.5mm and retained on 10mm sieve was used. The gravity of coarse aggregate is 2.70. Crushed coarse aggregate and grit conforming to IS 383-1987 was used. Coarse aggregate of size 20mm down Physical Properties of Coarse Aggregate are as shown in Table 3

Sl.No.	**Property**	**Value**
1	Specific Gravity	2.75
2	Bulk Density	16.05 kN/m^3
3	Water absorption	0.66%
4	Flakiness index	13.88
5	Elongation index	21.24
6	Crushing value	2.42
7	Impact value	16.1

Table 3: Physical Properties of Coarse Aggregate

4) Metakaolin:

Metakaolin is one of the innovative clay products developed in recent years. It is produced by controlled thermal treatment of kaolin. Metakaolin is obtained by calcination of pure or refined kaolintic clay at a temperature between 650^0C and 850^0C ,followed by grinding to achieve a fineness of 7000 to 9000 m^2/ kg. resulting material has high pozzolonicity.Metakaolin can be used as a concretreconstituent , replacing part of the cement content since it has pozzolanic properties. The use of metakaolin as a partial cement replacement material in mortar and concrete has been studied widely in recent years .despite of the recent studies , there are still many unknowns with the use of metakaolin . study is needed to determine the contribution of metakaolin to the performance of hardened concrete. If it is proven that the concrete is durable and strong , this will lead to the use of metakaolin to replace part of the cement. The specific gravity of metakaolin is 2.54. It is in conformity with the general requirements of pozzolona. Physical properties of Metakaolin as shown in Table 4

Appearance	**Off white powder**
Specific gravity	2.4 – 2.6
Density	2640 kg/m^3
Brightness	76%
Particle size	12µm
Residue on 375 mesh	Max 0.5%
Fineness	15000 – 30000 m^2/kg

Table 4: Physical Properties of Metakaolin

a) Chemical Composition:

Major constituents of Metakaolin are Sio_2 and Al_2o_3. typical chemical composition as given in table.Metakaolin must meet the requirements of ASTM C 618 , Standard Specification for Coal Fly ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete, Class N, with the following modifications

b) Uses of Metakaolin:

- High performance , high strength and lightweight concrete
- Precast concrete for architectural , civil , industrial ,and structural purpose
- Fibre cement and ferro cement products

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- Glass fibre reinforced concrete
- Mortars , stuccos , repair material , pool plasters
- Improved finishablity , colour and appearance

c) Advantages of Using Metakaolin:

- Increased compressive and flexural strength
- Reduced permeability
- Increased resistance to chemical attack
- Increased durability
- Reduced effects of alkali-silica reactivity (ASR)
- Reduced shrinkage due to particle packing, making concrete denser
- Enhanced workability and finishing of concrete Reduced potential for efflorescence

5) Fly ash

Fly ash, a principal by-product of the coal-fired power plants, is well accepted as a pozzolanic material that may be used either as a component of blended Portland cements or as a mineral admixture in concrete. In commercial practice, the dosage of fly ash is limited to 15%-20% by mass of the total cementitious material. Usually, this amount has a beneficial effect on the workability and cost economy of concrete but it may not be enough to sufficiently improve the durability to sulfate attack, alkali-silica expansion, and thermal cracking. For this purpose, larger amounts of fly ash, on the order of 25%-35% are being used. Although 25%-35% fly ash by mass of the cementitious material is considerably higher than 15%-20%, this is not high enough to classify the mixtures as HVFA concrete according to the definition proposed by Malhotra and Mehta . From theoretical considerations and practical experience the authors have determined that, with 50% or more cement replacement by fly ash, it is possible to produce sustainable, highperformance concrete mixtures that show high workability, high ultimate strength, and high durability. The following text containing a brief description of the composition and properties of HVFA concrete is adapted from Malhotra and Mehta's book on HVFA concrete

IV. EXPERIMENTAL PROGRAMME

The objectives of the present Study are:

- To conduct all the preliminary tests on the materials used like cement, sand, aggregates.
- By using Indian Standard the Mix Design procedure is adopted (IS 10262 – 2009)
- To partially replace cement with Metakaolin and Fly Ash
- To conduct tests on plain concrete and cement replaced with Metakaolin and Fly Ash concrete in wet state like compaction factor test and in hardened state like compressive strength test, split tensile strength test and flexural strength test
- Testing of Cubes, cylinder, and prisms at different curing period
- To compare the strength behavior of M25 grade concrete and draw the graphs between relative strengths for different percentage replacements of cement by Fly Ash and Metakaolin
- To decide the optimum percentage replacement of Fly Ash and Metakaolin
- Required to fetch the maximum strength for M25 grade of concrete.
- Estimating of quantities for control specimen and test specimen.

The experimental Program consist of casting and testing of 18 cubes, 18 cylinder and 18 prisms, are tested for 28 days. Metakaolin were added in steps of 5% (0%, 5%, 10%, 15%, 20% & 25%) & Fly Ash 5%%.

For each mix 3 cubes, 3 cylinders & 3 prisms were casted for 28 days

A. Casting and Curing of Control Specimen:

The standard size of (150mm x 150 mm x 150 mm) cube moulds, standard size of (150 mm x 300 mm) cylinder moulds, standard size (100mm x 100 mm x 500 mm) prisms, are casted. Cube, cylinder, prism are made up of cast iron for casting. Before pouring the fresh concrete. The moulds are cleaned and the corners are pasted with oil. One coat of cutting oil is applied on all internal surfaces. The moulds are filled in three layers and the height of each layer is about 1/ 3rd height of mould, each layer is compacted by giving blows with a tamping rod over the entire cross section uniformly for CVC member and less compaction is done for METAKAOLIN members. After filling and compacting the moulds, the top surface are made smooth and kept for a period for 24 hours. Then the mould is removed and the cubes, cylinder, prism are kept under water for 7 and 28 days. The water should be clean and free from impurities. The water should be changed for every three days to obtained good results. Then after completing the curing period all the specimen should be removed and kept for drying for one day, because it should be completely dried to obtained good results. The surface of the specimens should be cleaned and the test is carried out under compressive testing machine and universal testing machine.

Fig. 1

V. RESULTS AND DISCUSSIONS

A. Tests for Compressive Strength:

The compressive strength of concrete is one of the most important properties of concrete in most structural application concrete is implied primarily to resist compressive stress.

In this investigation, conventional concrete and concrete cube were used for testing the compressive

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strength. The cubes are tested in a compressive testing machine of capacity 200KN. The load has been applied at the rate of 315KN/min. The load applied in such a way that the two opposite sides of the cube are compressed. The load at which the control specimens ultimately fail is noted. The average strength of 3 cubes is taken as compressive strength. Compressive Strength values at 28 days is as shown in Table 5 and Graph 1

Compressive strength is calculated by dividing load by area of specimen.

$fc = P/A$

Where

Fc = cube compressive strength in N/mm^2

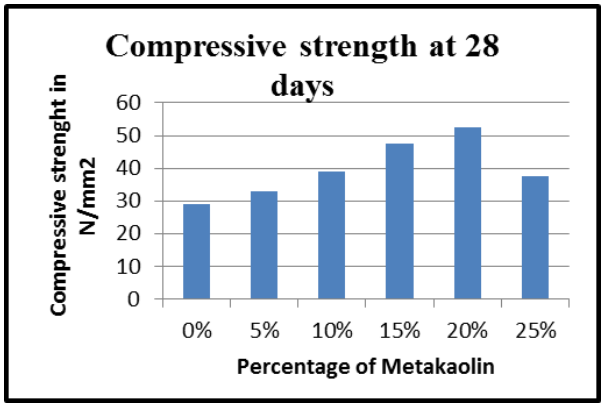
P = cube compressive causing failure in N

A = cross section area of cube.

Fig. 2: Compressive Strength Test

Replacement level		Compressive strength(N/mm^2)
Metakaolin	Fly ash	28 days
0%	0%	29.03
5%	5%	32.84
10%	5%	39.02
15%	5%	47.59
20%	5%	52.46
25%	5%	37.71

Table 5



Graph 1: Compressive Strength at 28 Days of Age At 5% of Fly Ash and Metakaolin

B. Tests for Split Tensile Strength:

The tensile strength of concrete is most often evaluated using a split cylinder test, in which a cylindrical specimen is placed on its side and loaded in diametrical compression, so to induce transverse tension. Practically, the load applied on the cylindrical concrete specimen induces tensile stresses on the plane containing the load and relatively high compressive stresses in the area immediately around it. When the cylinder is compressed by the two plane-parallel faceplates, situated at two diametrically opposite points on the cylinder surface then, along the diameter passing through the two points, the major tensile stresses are developed which, at their limit, reach the fracture strength value, "fcs"

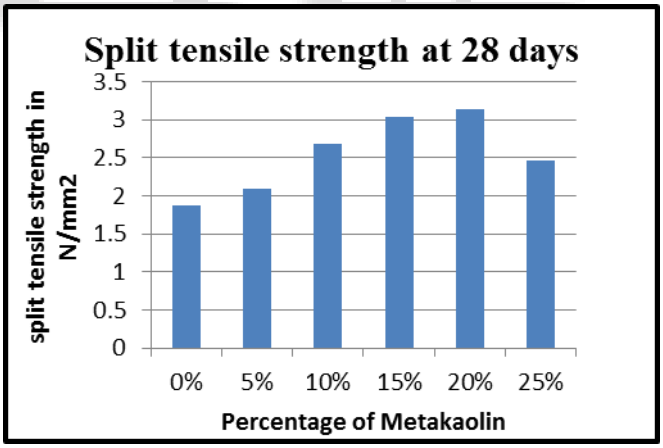
$$fcs = 2F/\pi dl$$

Where: F is the fracture compression force acting along the cylinder generatrix, d is the cylinder diameter; l is the cylinder length. Split tensile strength at 28days are as shown in Table 6 and Graph 2

Fig. 3

Replacement level		Split tensile strength
Metakaolin	Fly ash	28 days
0%	0%	1.87
5%	5%	2.10
10%	5%	2.69
15%	5%	3.14
20%	5%	3.12
25%	5%	2.47

Table 6



Graph 2: Split Tensile Strength at 28 Days of Age At 5% of Fly Ash and Metakaolin

C. Tests for Flexural Strength:

This test is performed according to IS 516 – 1959. The flexural strength of the specimen shall be expressed as the modulus of rupture *f*b, which, if '*a*' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq cm as follows:

$$fb = p*l/ bd^2$$

b = measured width in cm of the specimen,

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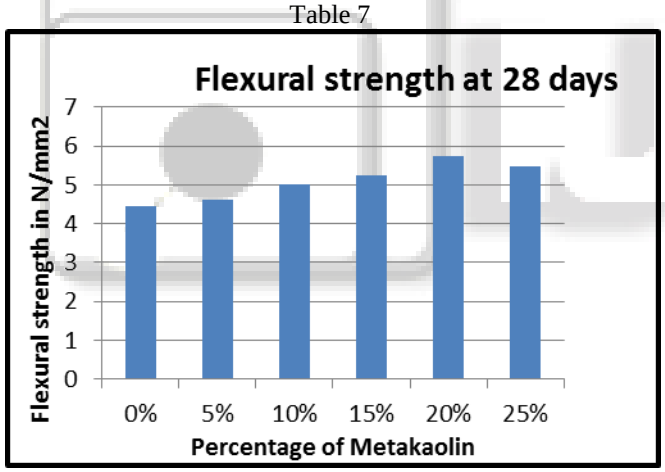
d = measured depth in cm of the specimen at the point of failure,
l = length in mm of the span on which the specimen was supported,
p = maximum load in kg applied to the specimen
Flexural strength at 28 days are as shown in Table 7 and Graph 3

Fig. 4

Replacement level		Flexural strength
Metakaolin	Fly ash	28 days
0%	0%	4.44
5%	5%	4.63
10%	5%	5.01
15%	5%	5.26
20%	5%	5.74
25%	5%	5.47

Table 7



Graph 3: Flexural Strength at 28 Days of Age At 5% of Fly Ash and Metakaolin

VI. Conclusion

Following observations have been made from the study of using Fly Ash and metakaolin in concrete:

- The 28 day Compressive strength increases with increase in percentage of metakaolin for all the mixes while in case of Fly Ash strength increases upto 15% replacement level and then starts decreasing. And the 7 day compressive strength of concrete generally decreases with the increasing Metakaolin content at all the Fly Ash contents.
- Split tensile strength in Metakaolin with 5% Fly Ash content is found to be more. In this case after 28 days curing the strength has increased more than 7 days curing.
- In Split Tensile Strength, the difference between 7 days strength and 28 days strength is large.
- The 28 day Flexural strength increases with increase in percentage of metakaolin for all the mixes while in case of Fly Ash strength increases upto 15% replacement level and then starts decreasing.
- The slump is found to decreases with increase in Metakaolin content at all the Fly Ash contents considerably.

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