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Paper Authors

D.RAMYA , DR. CH.BHAVANNARAYANA

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MECHANICAL PROPERTIES INVESTIGATION OF CEMENT REPLACED WITH POZZOLANIC MATERIALS

D.RAMYA *, DR. CH.BHAVANNARAYANA **
*PG Scholar ,Kakinada Institute of Engineering and Technology - II, Korangi, Kakinada
** Professor & HOD, Kakinada Institute of Engineering and Technology - II, Korangi, Kakinada

ABSTRACT: With the recent rapid increase in population the need for infrastructure development increased exponentially. This increased demand for new infrastructure is feeding the global demand for building materials like ordinary Portland cement (OPC), which is the main binding constituent for producing concrete. Currently, the global demand of the OPC is around 4 billion tons , which is second most required material after water and it is expected that this figure will increase by 8–10% in the coming years . The production of cement is a highly energy intensive process which releases one-tonne of carbon dioxide (CO2) for every tonne production of cement. It is estimated that by theyear2020,the CO2emission will rise by 50% from the current levels. These findings have put increased pressure on the concrete construction industry, thus, a key challenge is to reduce the amount of cement used in concrete mixtures. Replacing Portland cement with mineral admixtures such as fly ash, blast furnace slag (BFS), and silica fume has been a widely adopted strategy due to their pozzolanic reactivity and latent hydraulic activity . Hence, the researchers are currently focusing on waste material having cementing properties, which can be added as partial replacement of cement which reduces cement production then the Green House gasses emission is also reduced. It aids in sustain-able management of the industrial waste. The concrete industry is constantly looking for supplementary cementations material with the objective of reducing the solid waste disposal problem. In this research, the effect of metakaolin and fly ash on strength of concrete was investigated. Results show that partial replacement of cement by 30% fly ash leads to a decrease relevantly early in compressive strength, when compared to a reference mix of 100% Portland cement. Results also show that using 30% fly ash and 15% metakaolin replacement is responsible for minor strength. But 15% metakaolin shows outstanding strength results when compared to a control mix.

Keywords: metalaolin, fly ash, ordinary Portland cement, fine aggregate

1.INTRODUCTION

1.1 GENERAL: The advancement of concrete technology can reduce the consumption of natural resources and energy sources and lessen the burden of pollutants on environment. Presently large amounts of Metakaoline, a dehydroxylated form of the clay mineral kaolinite came into existence. This project describes the feasibility of using in concrete production as partial replacement of cement.

In India, the Metakaoline and Fly ash are the most thriving industrial effects. These contain physical and mechanical properties of fresh and hardened concrete that have been investigated. Slump and air content of fresh concrete and absorption and compressive strength of hardened concrete were also investigated. Test results show that this Metakaoline and Fly ash are capable of improving hardened concrete performance up to 10%, Enhancing fresh concrete behavior and can be used in architectural concrete mixtures. The compressive strength of concrete was measured for 7 and 28 days. In order to evaluate the effects of Metakaoline and Fly ash on mechanical behavior, many different mortar mixes were tested.

1.2 METAKAOLIN:

The Concrete Countertop Institute recommends using met kaolin as a cement replacement in concrete countertop mixes, instead of other pozzolans such as silica fume, to:

- Boost compressive strength
- Make finishing easier
- Reduce efflorescence
- Mitigate alkali-silica reaction
- Maintain colour, especially in white concrete

Table 1: shows the Chemical compositions of Metakaolin. The chemical composition of Metakaolin is similar to Portland cement

Chemicals	Percentage (%)
SiO2	62.62
Al2O3	28.63
Fe2O3	1.07
MgO	0.15
CaO	0.06
Na2O	1.57
k2o	3.46
TiO2	0.36
LOI	2

1.3 FLY ASH: Fly ash is a burnt and powdery derivative of inorganic mineral matter that generates during the combustion of pulverized coal in the thermal power plant. The burnt ash of the coal contains mostly silica, alumina, calcium and iron as the major chemical constituents. Depending on the burning temperature of coal, the mineral phases in crystalline to non-crystalline structures such as quartz (SiO2), mullite (3Al2O3 2 H2O), hematite (Fe2O3), magnetite (Fe3O4), wustite (FeO), metallic iron, orthoclase (K2O Al2O36 SiO2) and fused silicates usually occur in the burnt coal ash2. Silica and alumina account for about 75 to 95 % in the ash. The classification of thermal plant fly ash is considered based on reactive calcium oxide content as class-F (less than 10 %) and class-C (more than10 %). Indian fly ash belongs to class-F. The calcium bearing silica and silicate minerals of ash occur either in crystalline or non-crystalline structures and are hydraulic in nature they easily reacts with water or hydrated lime and develop pozzolanic property. But the crystalline mineral phases of quartz and mullite present in the ash are stable structures of silica and silicates, and are non-hydraulic in nature. Usually the fly ash

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contains these two mineral phases as the major constituents. Therefore, the utilisation of fly ash in making building materials like fibre cement sheets largely depends on the mineral structure and pozzolanic property. Fly ash is broadly an aluminium-silicate type of mineral rich in alumina and silica.

Table 2: Chemical Composition of fly ash

Chemicals	Percentages
SiO2	60.5
Al 2O3	30.8
Fe2 O3	3.6
CaO	1.4
MgO	0.91
SO3	0.14
K2O +Na2O	1.1
LOI	0.8

2. LITERATURE REVIEW

Teja Kiran Ch [17] et al. (2016) in his paper "Strengthening of concrete by partial replacement of cement with fly ash and Metakaolin mix" deals with the effect of mineral admixtures incorporated with cement replacement and keeping the water cement ratio same for the ordinary concrete and modified concrete. 0, 5, 10, 15, 20, 30 percentages of fly ash and Metakaolin was partially replaced to cement and the best proportion that give the maximum strength was obtained. Concrete mix of M20 grade was used for the experimental investigation. The compressive strength and the flexural strength of the concrete were tested. Optimum percentage of Metakaolin alone and fly ash alone was determined and the optimum percentages of the two materials were combined to find the best proportion in case of compressive as well as flexural strength. The specimens, cubes and beams were tested after 7 days and 28 days of curing. The comparison of the results between the control specimen and the modified concrete were done.

Usha K [18] et al. (2016) conducted a study on "Suitability of Fly Ash in Replacement of Cement in Pervious Concrete". The study investigates the effects on the important engineering properties of pervious concrete with the use of fly ash The physical properties examined include compressive strength, flexural strength, split tensile strength and permeability of pervious concrete. The cement was replaced by 0, 10, 20 and 30 percentages fly ash. Concrete mix of M15 grade pervious concrete was used for the experimental study with varying percentages of cementitious materials. Water and super plasticizer in liters are used in the mix. Based on the results of trial mix the proportions which is resulted in higher compressive strength value with good workability is selected for the final mix, to find 28th day compressive strength and other strength properties. The specimens, cubes and cylinders were tested for compressive strength and split tensile strength with 7 days and 28 days of curing. From the results of considered parameters, it is observed that 20% replacement of cement with fly ash showed better performance compared to previous concrete without fly ash.

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3.MATERIALS AND METHODOLOGY

MATERIALS

3.1 MATERIALS USED

The materials used in the project are as follows:

- Cement
- Fine aggregate
- Coarse aggregate
- Water
- Metakaolin
- Fly Ash

CEMENT

The cement used for this present study JPJ (OPC 53) grade cement conforming all conditions of IS 8112-1989. It is most recently manufactured, is of uniform color and also free of lumps. The physical property of the cement is determined considering codal provisions. Fineness of cement, normal consistency, specific gravity, setting time, soundness test, and compressive strength of cement, is determined.

Table -3: cement physical properties:

Properties	Results
Fineness of cement	OPC 53 – 6%
Normal consistency	32
Specific gravity	3.15
Setting time Initial Final	 40 mints 330mints
Soundness of cement	2mm
Compressive Strength of Cement Motor cubes for 3 days 7 days 28 days	 29 37.83 53.6

FINE AGGREGATE:

The sand which is used is comes under Zone –III as per IS 383-1970. The physical properties like zoning of sand, bulk density, specific gravity are determined according to the codal provisions Sieve analysis of fine aggregate

Table -4: physical properties of fine aggregate:

Properties	Test results
Specific gravity	2.52
Fineness modulus	2.2
Bulk density	1.69

COARSE AGGREGATE:

The coarse aggregate used is from well-established quarry, satisfying the code IS 383:1970. The mixture of coarse aggregates is used of only 20 mm .the material is of uniform color and has good angular shape. The physical properties like fineness-modulus, specific-gravity bulk-density, water-absorption, aggregate-impact, and crushing value.

3.2 MIX DESIGN:

The mix design was done by using the guidelines of IS Code method (IS10262-2009). The design stipulations and the data considered for mix design has been presented below.

STIPULATIONS AND TEST DATA FOR MATERIALS:

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A) Type of cement	OPC 53 grade
B) Maximum size of aggregate	20 mm
C) Minimum cement content	320 Kg/m^3
D) Maximum water cement ratio	0.45
E) Workability	50mm (slump)
F) Exposure condition	Severe(RCC)
G) Method of placing concrete	by hand
H) Degree of super vision	Good
I) chemical admixture	Not used
J) Specific gravity of cement	3.15
K) Specific gravity of Metakaolin	2.6
L) Specific gravity of Fly ash	2.2
M) Specific gravity of coarse aggregate	2.8
N) Specific gravity of Fine aggregate	2.70
O) Water absorption	
1) Course aggregate	0.5%
2) Fine aggregate	Nil
P) Free surface moisture	
1) Coarse aggregate	nil
2) Fine aggregate	1.5%

Q) Grading of coarse aggregate is conforming to table 2 of I S 383 and grading of fine aggregate is falling under zone 2.

3.3 MIX DESIGN PROCEDURE:

3.3.1 TARGET STRENGTH FOR MIX PROPORTIONING:

$$f'ck = fck + 1.65\, s$$

where,

f'ck = target average compressive strength at 28 days,

fck = characteristic compressive strength at 28 days, and

s = standard deviation.

standard deviation, *s* =5 N/mm^2

Therefore, target strength = 35 + 1.65 x 5
= 43.25 N/mm^2

3.3.2 SELECTION OF WATER CEMENT RATIO

The target strength 43.25 n/mm^2 can be achieved in 28 days by using the water cement ratio (w/c) of 0.46

But as per table 5 of I S 456, a maximum w/c ratio permitted is 0.45

Therefore, adopt water cement ratio (w/c) of 0.45

3.3.3 SELECTION OF WATER CONTENT

maximum water content for 20 mm aggregate = 186 litre (for 25 to 50 mm slump range)

As super plasticizer is not used, the water content can't be reduced.

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3.3.4 CALCULATION OF CEMENT CONTENT

Water cement ratio (w/c) = 0.45

Cement content = 186/0.45

= 413 kg/m^3

From Table of IS 456

Minimum cement content for 'severe' exposure condition = 320 kg/m3

413 kg/m^3 > 320 kg/m^3, hence, O.K.

Now, to proportion a mix containing fly ash and metakaolin the following steps are suggested:

a) Decide the percentage fly ash to be used based on project requirement and quality of materials

b) In certain situations increase in cementitious material content may be warranted, The decision on increase in cementitious material content and its percentage may be based on experience and trial.

3.3.5 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE

From Table volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate falling under (Zone II) and water-cement ratio of 0.50 =0.62

In the present case W/C is o.45

Volume of coarse aggregate required to be increased to decrease the fine aggregate content

As the w/c ratio is lowered by 0.05, the proportion of volume of coarse aggregate is increased by

= (0.01/0.05)*0.05

= 0.01

Therefore, corrected proportion of volume of coarse aggregate for the w/c ratio of 0.45 = 0.62+0.01

= 0.63m^3

Volume of fine aggregate = 1 – 0.63

= 0.37m^3

3.4 MIX CALCULATIONS

Volume of concrete = 1m^3

Absolute volume of cement = (413/3.15)*1/1000

= 0.1311m^3

Volume of water = 186

= 0.186 m^3

Therefore,

= 0.1311+0.186

= 0.3171 m^3

Final weight of aggregate = 1- 0.3171

= 0.6829 m^3

Weight of coarse aggregate

=(*f* x volume of coarse aggregate x Specific gravity of coarse aggregate x I 000)

= 0.682*0.63*2.80*1000

= 1203.048m^3

Weight fine aggregate = (*f* x volume of fine aggregate x Specific Gravity of fine aggregate x 1000)

= 0.682 x 0.37 x 2.7 x 1000

= 681.318 m^3

Cement	Fine aggregate	Coarse aggregate	water
413 kg/m^3	681 kg/m^3	1203 kg/m^3	186kg/m^3

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Field correction:
Absorption of fine aggregate = 681 x 1/100
= 6.81 kg/m^3
Absorption of coarse aggregate = (0.5/100) x 1203
= 6.015
Therefore,
Fine aggregate = 681 – 6.81
= 674 kg/m^3
Coarse aggregate = 1203 – 6.015 = 1196.9 kg/m^3
Water content = 186+6.81+6.015
= 198.82 kg/m^3
Therefore, the mix proportion is

cement	Fine aggregate	Coarse aggregate	water
413	674	1196	198

In the normal ratio the proportion is

cement	Fine aggregate	Coarse aggregate	water
1	1.63	2.89	0.479

For a cube of dimensions 150mm x 150mm x 150mm the material proportion is taken as below

$$1x+1.63x+2.89x+0.479x = 8.25$$
$$5.999x = 8.25$$
$$X = 1.37$$

Figure 1 : Cube mould

Therefore, the proportion for one cube of size 150mm x 150mm x 150mm is

Cement	Fine aggregate	Coarse aggregate	water
1.375	2.241	3.97	0.658

This is also called as control mix.
For tensile test the cylinders is of the following dimensions
Diameter of cylinder = 150 mm
Height of cylinder = 300 mm
Ideal weight of cylinder = 14 kg

Figure 2 : cylindrical mould

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3.5 EXPERIMENTAL WORK

3.5.1 MIX PROPORTIONS:

For each percentage 2 sets of cubes and 2 sets of cylinders to be casted i.e. For 7 days and 28 days

For 15% replacement of metakaolin to cement the proportion for 1 cube of dimensions 150mm x 150mm x 150mm is

Met kaolin	Cement	Fine aggregate	Coarse aggregate	water
0.206	1.169	2.241	3.97	0.658

For 30% replacement of fly-ash to cement the proportion for 1 cube of dimensions 150mm x 150mm x 150mm is

Fly-ash	Cement	Fine aggregate	Coarse aggregate	Water
0.412	0.962	2.241	3.97	0.658

For 15% met kaolin and 30% fly-ash replacement to cement the proportion for 1 cube of dimensions 150mm x 150mm x 150mm is

metakaolin	Fly-ash	Cement	Fine aggregate	Coarse aggregate	water
0.206	0.412	0.757	2.241	3.97	0.658

4.RESULTS AND DISCUSSIONS

4.1 CONTROL MIX

Table 5 : Data for 7days strength results of control mix

For 7 days curing the results are:

Cubes	Cylinders
1) 26.3 N/mm^2	1) 7.72 N/mm^2
2) 23.9 N/mm^2	2) 8.31 N/mm^2
3) 22.6 N/mm^2	
Average compressive strength =24.26 N/mm^2	Average tensile strength = 8.01 N/mm^2

Table 6: Data for 28 days strength results of control mix

For 28 days curing results are:

Cubes	Cylinders
1) 42.2 N/mm^2	1) 12.67 N/mm^2
2) 45.4N/mm^2	2) 10.6 N/mm^2
3) 47.5N/mm^2	
Average compressive strength =45.03 N/mm^2	Average tensile strength = 11.63 N/mm^2

4.2 REPLACEMENT OF METAKAOLIN:

For 15% metakaolin replacement to cement results: **Table 7**: Data for 7 days strength of metakaolin replacement

For 7 days curing , the results are

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Cubes	cylinders
1) 32.7 N/mm^2	1) 7.77 N/mm^2
2) 28.10 N/mm^2	2) 9.41 N/mm^2
3) 30.96 N/mm^2	
Average compressive strength =30.58 N/mm^2	Average tensile strength = 8.59 N/mm^2

Table 8: Data for 28 days strength of metakaolin replacement

For 28 days curing, the results are

Cubes	cylinders
1) 50.96 N/mm^2	1) 18.32 N/mm^2
2) 52.96 N/mm^2	2) 14.43 N/mm^2
3) 48.6 N/mm^2	
Average compressive strength = 50.84 N/mm^2	Average tensile strength = 16.375 N/mm^2

4.3 REPLACEMENT OF FLYASH:

For 30% replacement of fly ash to cement results is

Table 9: Data for 7 days strength of fly ash replacement

For 7 days curing, the results are

Cubes	Cylinders
1) 17.4 N/mm^2	1) 5.67 N/mm^2
2) 20.3 N/mm^2	2) 4.85 N/mm^2
3) 18.7 N/mm^2	
Average compressive strength =18.8 N/mm^2	Average tensile strength = 5.26 N/mm^2

Table 10: Data for 28 days strength of fly ash replacement

For 28 days curing, the results are

Cubes	Cylinders
1) 38.67 N/mm^2	1) 9.68 N/mm^2
2) 40.8 N/mm^2	2) 8.78 N/mm^2
3) 38.76 N/mm^2	
Average compressive strength =39.41 N/mm^2	Average tensile strength = 9.23 N/mm^2

4.4 REPLACEMENT OF METAKAOLIN AND FLYASH:

For 15% metakaolin and 30% fly ash replacement to cement results are

Table 11: Data for 7 days strength of both Metakaolin and flyash

For 7 days curing, the results are

Cubes	Cylinders
1) 21.9 N/mm^2	1) 6.8 N/mm^2
2) 25.6 N/mm^2	2) 7.33 N/mm^2

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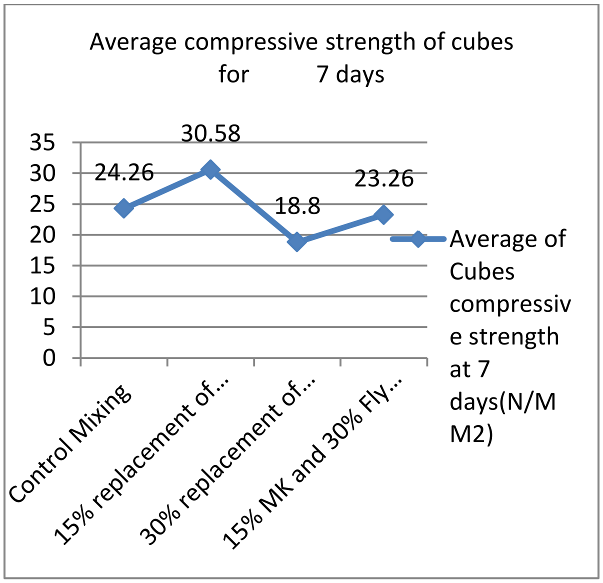
3) 22.3 N/mm^2	
Average compressive strength =23.26 N/mm^2	Average tensile strength = 7.13 N/mm^2

Table 12: Data for 28 days strength of both Metakaolin and flyash

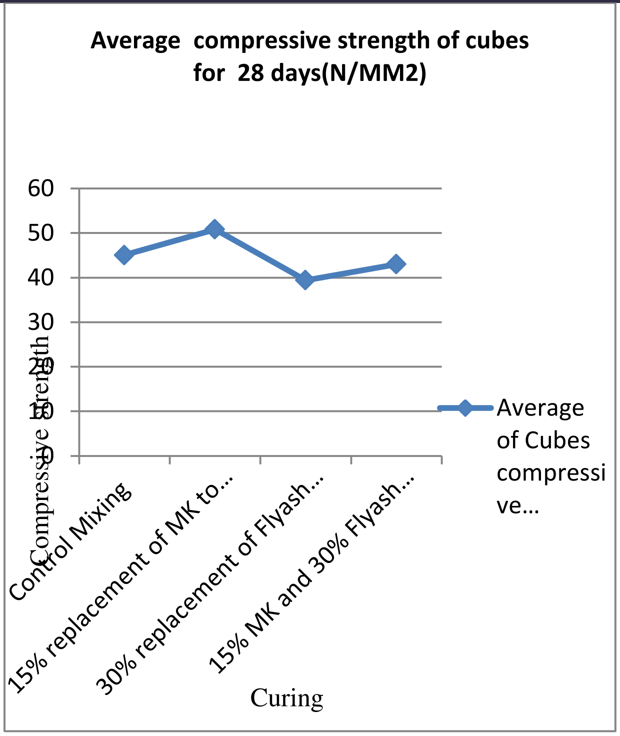
For 28 days curing, the results are

Cubes	Cylinders
1) 40.6 N/mm^2	1) 9.42 N/mm^2
2) 42.4 N/mm^2	2) 11.68 N/mm^2
3) 45.34 N/mm^2	
Average compressive strength =43 N/mm^2	Average tensile strength = 10.55 N/mm^2

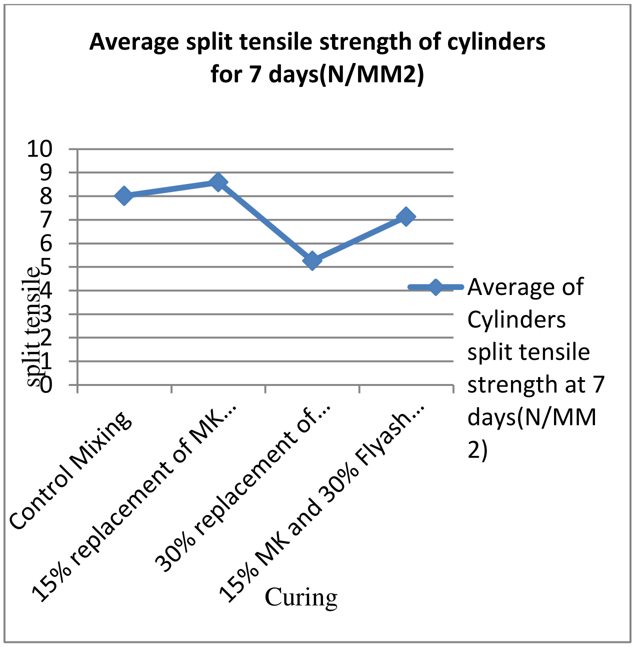
4.5 TABLES AND GRAPHS:



Graph No 1 Avg of cubes compressive strength for 7 days



Graph No 2 Average compressive strength of cubes for 28 days



Graph No 3 Avg split tensile strength of cylinders for 7 days

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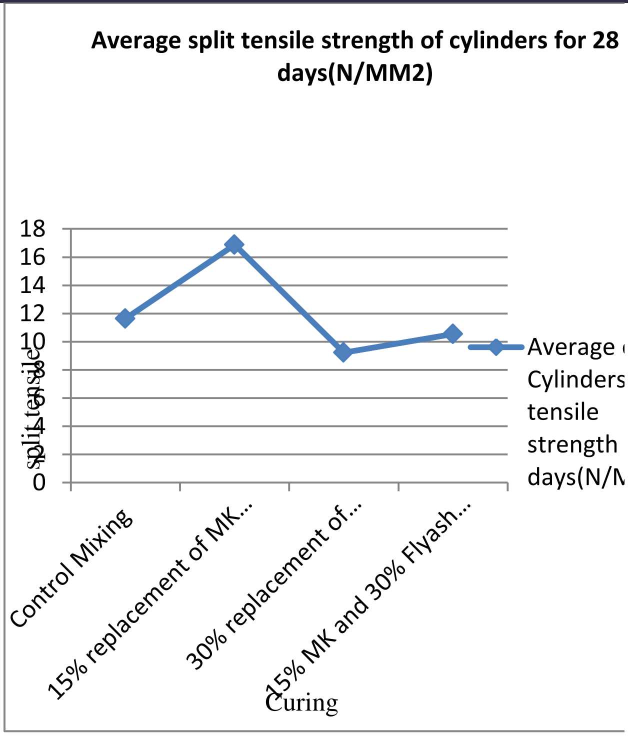
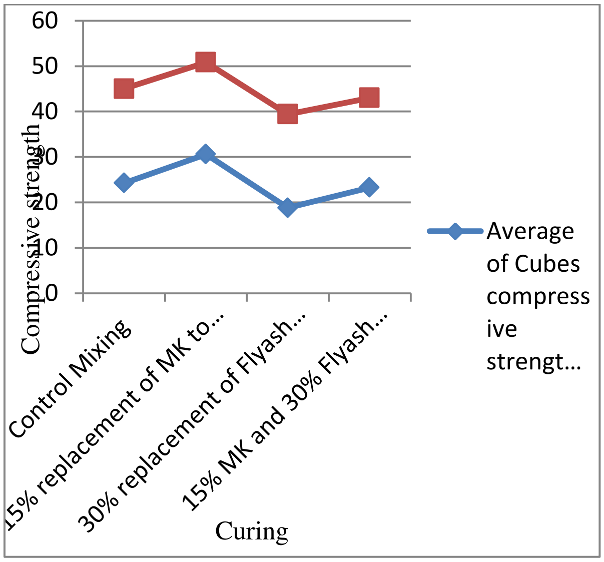
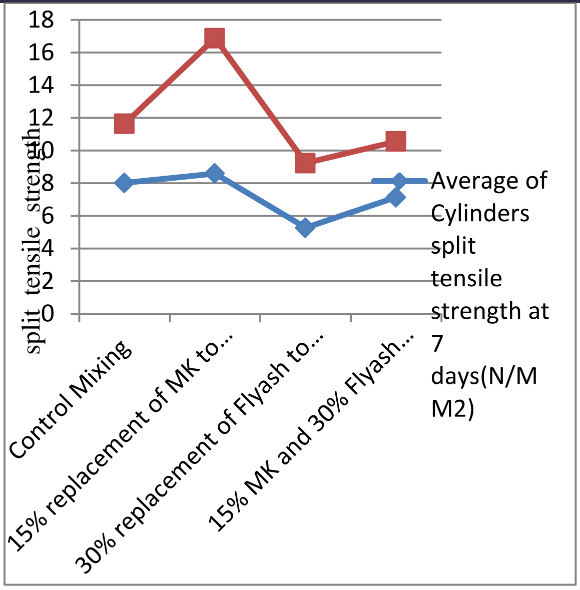


Graph No 4 Average split tensile strength of cylinders for 28 days



Graph No 5 Comparison of Compressive Strength for 7 and 28 days



Graph No 6 Comparison of Split Tensile Strength of cylinders for 7 and 28 days

CONCLUSIONS

1. The compressive strength result of concrete when replaced up to 30 % of fly ash is less than conventional aggregate concrete at the end of 7,28 days for normal curing
2. The compressive strength result of concrete when replaced up to 15 % of metakolin is more than conventional aggregate concrete at the end of 7,28 days for normal curing
3. The compressive strength result of concrete when replaced up to 30 % of fly ash and 15% metakolin is less than conventional aggregate concrete at the end of 7,28 days for normal curing
4. The split tensile strength result of concrete when replaced up to 30 % of fly ash is less than conventional aggregate concrete at the end of 7,28 days for normal curing

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5. The split tensile strength result of concrete when replaced up to 15 % of metakolin is more than conventional aggregate concrete at the end of 7,28 days for normal curing
6. The split tensile strength result of concrete when replaced up to 30 % of flyash and 15% metakolin is less than conventional aggregate concrete at the end of 7,28 days for normal curing

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