A Study on Strength Properties of Metakaolin and Flyash Based Concrete

THANNIRU RAJKUMAR[1], G. EZRI BABU[2]
[1]*PG-Student, PACE Institute of Technology and Sciences*
[2]*Assistant Professor, PACE Institute of Technology and Sciences*

***Abstract*— Partial replacement of Portland cements by pozzolanic and cementitious by-products or mineral additions that allow for carbon dioxide emission reductions is a major issue in the current climate change context. However, the use of low pozzolanic activity by-products like fly ash can cause a decrease relatively early in compressive strength. In this paper, 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.**

***Index Terms*— Concrete, Cement, Fly Ash, Metakaolin, Strength.**

I. INTRODUCTION

Improvement of quality of structural materials is a general trend which may be observed in our civilization. At different periods that trend has a steady continuous function or of a step function. High Performance Concretes appeared a few years ago and now develop rapidly representing a new generation of composite materials in building and civil engineering. Without any doubt their application will be increased in many kinds of structures where special requirements are imposed. Although Portland cement demands are decreasing in industrial nations, it is increasing dramatically in developing countries. Cement demand projections shows that by the year 2050 it will reach 6000 million tons. Portland cement production leads to major CO2 emissions, results from calcination of limestone (CaCO3) and from combustion of fossil fuels, including the fuels required to generate the electricity power plant, accounting for almost 0.7 tons of CO2 per ton. Of cement which represents almost 7% of the total CO2 world emissions. This is particularly serious in the current context of climate change caused by carbon dioxide emissions worldwide, causing a rise in sea level and being responsible for a meltdown in the world economy. Since Portland cement is used mostly in concrete production, the most important building material on Earth (10.000 billion tons per year), partial replacement by pozzolanic by-products and mineral additions will allow relevant carbon dioxide emissions reductions. Investigations about the pozzolanic properties of fly ash, calcined clays and calcined agriculture wastes were already carried out. Pozzolanic admixtures react with Ca (OH) generating additional CSH phases, resulting in a more compact concrete with increase durability. Some supplementary cementitious material, like fly ash has very slow hydration characteristics thus providing very little contribution to early age strength while others like metakaolin possess a high reactivity with calcium hydroxide having the ability to accelerate cement hydration. Since current concrete structures present a higher permeability level that allows aggressive elements to enter, leading corrosion problems using pozzolanic admixtures not only reduce carbon dioxide emissions but also allow structures with longer service life, thus lowering their environmental impact. Nevertheless, studies on the durability performance of concrete containing pozzolanic by-products are recent and still scarce. Even scarcer about the durability performance of concrete that contains blended reactive pozzolans. This paper presents experimental data about the strength and durability performance of metakaolin, fly ash based concrete.

II. LITERATURE REVIEW

Sabir.B.B et al (2021): Carried out a study on the utilization of Metakaolin as pozzolanic material for mortar and concrete and mentioned about the wide range application of Metakaolin in construction industry .They reported that the usage of Metakaolin as a pozzolana will help in the development of early strength and some improvement in long term strength. They mentioned that Metakaolin alters the pore structure in cement paste mortar and concrete and greatly improves its resistance to transportation of water and diffusion of harmful ions which lead to the degradation of the matrix.

Jian-Tong Ding et al (2022): Experimentally found out the effects of Metakaolin and Silica Fume on the properties of Concrete. Experimental investigation with seven concrete mixtures of 0, 5, 10, and 15% by mass replacement of cement with high-reactivity Metakaolin or Silica fume, at a water cement ratio of 0.35 and a sand-to-aggregate ratio of 40% was carried out. The effect of Metakaolin or Silica fume on the workability, strength, shrinkage, and resistance to chloride penetration of concrete was investigated. In corporation of both Metakaolin and Silica fume in concrete was found to reduce the free drying shrinkage and restrained shrinkage cracking width. It is also reported that the incorporation of Metakaolin or Silica fume in concrete can reduce the chloride diffusion rate significantly. The performance of Silica fume was found to be better than Metakaolin.

Justice.J.M et al (2015): Made a comparative study by replacing 8% by weight of cement with Metakaolin and Silica fume. Metakaolin addition proved to be beneficial, resulting in concrete with considerably higher strengths and greater durability than the normal mixes. The use of finer Metakaolin was more effective in improving concrete properties than the coarser Metakaolin. Addition of Metakaolin increased the use of super plasticizers. Addition of Metakaolin exhibited improvements in shrinkage, durability and other strength aspects.

Nabil M. Al-Akhras (2015) :Carried out an investigation by replacing cement with Metakaolin to find out the durability of concrete against sulphate attack. Three replacements of cement with Metakaolin (5, 10 and 15% by weight) were done with water cement ratio of 0.5 and 0.6. After the specified days, the samples were immersed in 5% sodium sulphate solution for 18 months. The effect of metakaolin addition proved to be beneficial in improving the resistance of concrete to sulphate attack. Metakaolin with water cement ratio of 0.5 exhibited better results in sulphate resistance than 0.6. Autoclaved cured specimens had better resistance against sulphate than moist cured specimens.

Abid Nadeem et al (2018) :Made an investigation on the chloride permeability of high strength concrete and mortar specimens containing varying proportions of Metakaolin (MK) and Fly ash at elevated temperatures. A total of seven concrete and three mortar mixes were tested after exposing each mix to 200, 400, 600 and 800°C. In concrete, the dosage levels of MK were 5, 10 and 20% and for Fly ash the dosage levels were 20, 40 and 60%. In mortar, the dosage level of Metakaolin and Fly ash was 20%. All concrete specimens investigated in this study had a minimum compressive strength of 85 MPa. At normal temperatures, concrete and mortar specimens had very low chloride ion Penetrability. At normal temperature, metakaolin mixes had lower chloride permeability than Fly ash and Portland cement mixes. At normal temperatures, mortar specimens were more chloride permeable than concrete specimens. At 200°C and 400°C, mortar was still more chloride permeable than concrete but the ratio of mortar to concrete chloride permeability was less than that at normal temperature.

III. METHODOLOGY

The mix design was done by using the guidelines of IS Code method (IS10262-2019). The design stipulations and the data considered for mix design has been presented below.

STIPULATIONS AND TEST DATA FOR MATERIALS:

Type of cement	OPC 53 grade
Maximum size of aggregate	20 mm
Minimum cement content	320 Kg/m^3
Maximum water cement ratio	0.45
Workability	50mm (slump)
Exposure condition	Severe(RCC)
Method of placing concrete	by hand
Degree of super vision	Good
chemical admixture	Not used

Specific gravity of cement	3.15
Specific gravity of Metakaolin	2.6
Specific gravity of Fly ash	2.2
Specific gravity of C.A	2.8
Specific gravity of F.A	2.70
Water absorption	
Course aggregate	0.5%
Fine aggregate	Nil
Free surface moisture	
Coarse aggregate	nil
Fine aggregate	1.5%

MIX DESIGN PROCEDURE:
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.

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

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

SELECTION OF WATER CONTENT:
From Table 2, 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.

CALCULATION OF CEMENT CONTENT
Water cement ratio (w/c) = 0.45

Cement content = 186/0.45

= 413 kg/m^3

From Table 5 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.

PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE:
From Table 3, 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

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	FA	CA	Water
413 kg/m^3	681 kg/m^3	1203 kg/m^3	186 kg/m^3

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	FA	CA	Water
413	674	1196	198

In the normal ratio the proportion is

Cement	FA	CA	Water
1	1.63	2.89	0.479

IV. EXPERIMENTAL WORK

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

	Cement	FA	CA	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	FA	CA	Water
0.412	0.962	2.241	3.97	0.658

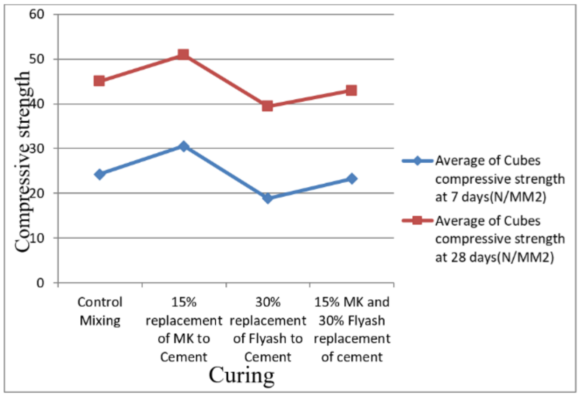
For 15% met kaolin and 30% fly-ash replacement to cement the proportion for 1 cube of dimensions 150mm x 150mm x 150mm is

Metakaolin	Fly-Ash	Cement	FA	CA	Water
0.206	0.412	0.757	2.241	3.97	0.658

IV. RESULTS AND DISCUSSION

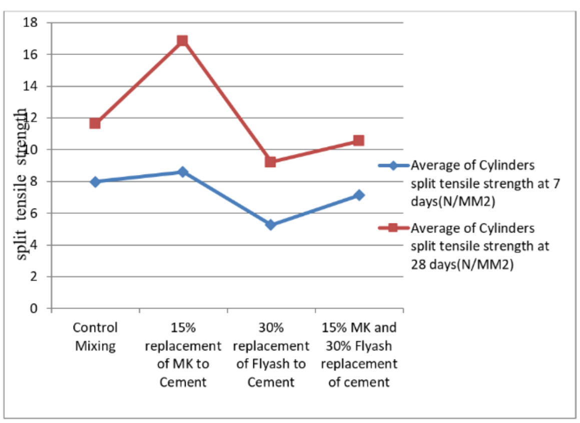
COMPRESSIVE STRENGTH:

Material	Avg. compressive strength of cubes for 7 days(N/MM^2)	Avg.compressive strength of cubes for 28 days(N/MM^2)
Control Mixing	24.26	45.03
15% replacement of MK to Cement	30.58	50.84
30% replacement of Fly ash to Cement	18.8	39.41
15% MK and 30% Fly ash replacement of cement	23.26	43



SPLIT TENSILE STRENGTH:

Material	Avg. split tensile strength of cubes for 7 days(N/MM^2)	Avg. split tensile strength of cubes for 28 days(N/MM^2)
Control Mixing	8.01	11.63
15% replacement of MK to Cement	8.59	16.878
30% replacement of Fly ash to Cement	5.26	9.23
15% MK and 30% Fly ash replacement of cement	7.13	10.55



CONCLUSION

- This paper confirms that partial replacement of Portland cement by 30% fly ash leads to serious decrease in compressive strength when compared to a reference mix of 100% Portland cement.
- The use of 30% fly ash and 15% metakaolin based mixtures are responsible for minor strength loss.
- The use of 15% metakaolin leads to 12% increase in compressive strength and 6% increase in split tensile strength when compared to control mix for 28 days

REFERENCES

[1] IS 10262 – 2009, for mix design procedure

[2] IS 456 – 2000, Indian standard guidelines for information on concrete

[3] M.S.SHETTY concrete technology

[4] Using metakaolin to improve the compressive strength and the durability of fly ash based Concrete . F. Pacheco Torgal*, Arman Shasavandi, Said Jalali

[5] Metakaolin- Pozzolanic Material For Cement in High Strength Concrete Sanjay N. Patil1, Anil K. Gupta2, Subhash S. Deshpande

[6] A REVIEW ON USE OF METAKAOLIN IN CONCRETE by Aiswarya S, Prince Arulraj G, Dilip C

[7] A Review on Use of Metakaolin in Cement Mortar and Concrete by Dr.K.Srinivasu1, M.L.N.Krishna Sai2, Venkata Sairam Kumar.N

[8] Effect of Metakaolin Content on the Properties of High Strength Concrete P. Dinakar*, Pradosh K. Sahoo, and G. Sriram .

[9] Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin by B. B. Patil1, P. D. Kumbhar

[10] Effect of Silica Fume and Metakaolin combination on concrete Vikas Srivastava1, Rakesh Kumar, Agarwal V.C, Mehta P. K

[11] ADVANTAGES OF USING FLY ASH AS SUPPLEMENTARY CEMENTING MATERIAL by JAGADESH . SUNKU

[12] Strength Studies on Metakaolin Blended High-Volume Fly Ash Concrete by M. Nazeer, R. Arun Kumar

[13] M. Nazeer, R. Arun Kumar. 2014. Strength Studies on Metakaolin Blended High-Volume Fly Ash Concrete, International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249-8958, 3(6).

[14] Sanjay N. Patil, Anil K. Gupta, Subhash S. Deshpande, Metakaolin- Pozzolanic Material For Cement in High Strength Concrete. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684, pp. 46-49.

[15] Davidovits J. 1988. Soft Mineralogy and Geopolymer. Proceedings of the Geopolymer 88 International Conference, the University de Technologie, Compiègne, France

[16] Molhotra V.M., Fly Ash, Slag, Silica Fume, and Rice Husk Ash in Concrete: A review, Concrete International, 15(4): 2-28, 1993.