Mechanical Properties for Cement Replacement by Metakaolin Based Concrete

J. Saravanan, K.Suguna, P.N.Raghunath

***Abstract*— This paper 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 M30 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 10%. 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.**

***Index Terms*— Flexural Strength, Metakaolin, Replacement, Tensile Strength**

I. INTRODUCTION

Concrete is one of the most common materials used in the construction industry. In the past few years, many research and modification has been done to produce concrete which has the desired characteristics. There is always a search for concrete with higher strength and durability. In this matter, blended cement concrete has been introduced to suit the current requirements. Cementitious materials known as pozzolans are used as concrete constituents, in addition to Portland cement. Originally the term pozzolan was associated with naturally formed volcanic ashesand calcined earths will react with lime at ambient temperatures in the presence of water. Recently, the term has been extended to cover all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess

cementitious properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica ofthe pozzolanic and calcium hydroxide, produced during the cement hydration reactions. In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolanic effect depends not only on the pozzolanic reaction, but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolanas to ordinary Portland cement (OPC) increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste. The current area of research in the concrete is introducing partial replacement of cement by metakaolin in the concrete. This paper presents experimental data about the strength performance of metakaolin based concrete.

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

Dhinakaran (2012) studied the strength increases by MK concrete is effective only at the early age of concrete and in the long term the strength increase is only marginal. The increase in compressive strength for MK concrete was greater especially at higher water cement ratios (i.e., 0.4 and 0.5) and hence more suitable for higher w/cm ratios. From the studies an optimum percentage of MK was found to be 10% for all w/cm ratios except for 0.32 and for 0.32 it was 15%. MK concrete higher increase in strength at early ages beyond 28 days it was found to be less than 10%. The maximum compressive strength of 59.25 N/mm^2 was observed at 0.4 w/cm with 10% MK. Addition of MK reduced the pH values, but the reduction is insignificant, since the pH values are still

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above 11.5, which will be helpful for maintaining the steel in a passive state itself. The depth of penetration of chloride ions for MK concrete is much lesser than control concrete. The minimum rate of reduction of chloride penetration depth for MK admixed concrete were arrived as 78%, 38%, 25% and 25% for w/cm ratios 0.32, 0.35, 0.40 and 0.50 respectively. The maximum rate of reduction was observed as 95% for 0.32 and 0.3 ratios.

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 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.

Patil (2012) studied the compressive strength of concrete increases with increase in HRM content up to 7.5%. Thereafter there is slight decline in strength for 10%, 12% and 15% due excess amount of HRM which reduces the w/b ratio and delay pozzolanic activity. The higher strength in case of 7.5% addition is due to sufficient amount of HRM available to react with calcium hydroxide which accelerates hydration of cement and forms C-S-H gel. The 7.5% addition of high reactivity metakaolin in cement is the optimum percentage enhancing the compressive strength at 28 days by 7.73% when compared with the control mix specimen. The 7.5% addition of high reactivity metakaolin in cement is enhanced the resistance to chloride attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 3.85% as compared with the reduction of strength of control mix specimen is by 4.88%. The 7.5% addition of high reactivity metakaolin in cement is also enhanced the resistance to sulfate attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 6.01% as compared with the reduction of strength of control mix specimen by 9.29%.
The present study deals with the compressive strength, split tensile strength and flexural strength for cement replacement by metakaolin based concrete.

II. MATERIALS

2.1 Concrete

The ingredient materials of concrete such as cement, fine aggregate and coarse aggregates are carried out. The test data for materials are presented in Table 2.1.

Table 2.1 Test Data for Materials

Materials	Values
Specific gravity of cement	3.04
Specific gravity of Metakaolin	2.54
Specific gravity of fly ash	2.34
Chemical admixture	Conflast 320
Specific gravity of coarse aggregate	2.73
Specific gravity of Fine aggregate	2.63
Fineness modulus of Coarse aggregate	7.21
Fineness modulus of Fine aggregate	2.61

2.2 Metakaolin

Metakaolin manufactured from pure raw material to strict quality standards. Metakaolin is a high quality pozzolanic material, which when blended with Portland cement improves the strength and durability of concrete and mortars. Metakaolin removes chemically reactive calcium hydroxide from the hardened cement paste. It reduces the porosity of hardened concrete. Metakaolin densities and reduces the thickness of the interfacial zone, thus improving the adhesion between the hardened cement paste and particulars of sand or aggregate. The

2.2 Mix Proportion

The M30 grade of concrete was used in the present investigation. The mix propitiations ordinary grade concrete and standard grade concrete was designed using IS: 10262-2009. The slump of fresh concrete is found as 50 - 75 mm.the specimen are kept immersed in water for 28 days. The chemical content of metakaolin was presented in Table 2.2. The mix proportions for conventional and volume based partial replacement OPC by Metakaolin and fly ash are presented in Table 2.3.

Fig. 1.1 Metakaolin

Table 2.2 Metakaolin Chemical Content: (Mass %)

[1] SiO_2 : 52	[2] TiO_2 : 0.65(max)	[3] Na_2O : 0.10(max)
[4] Al_2O_3 : 46	[5] CaO : 0.09(max)	[6] K_2O : 0.03(max)
[7] Fe_2O_3 : 0.6(max)	[8] MgO : 0.03(max)	[9]

Table : 2.3 M30 Mix for all Ratio

[10] [11] Specimen	[12] Cement Content [13] kg/m^3	[14] MK [15] [16] kg/m^3	[17] Fly Ash [18] [19] kg/m^3	[20] Fine [21] Aggregate [22] kg/m^3	[23] Coarse Aggregate [24] kg/m^3	[25] W/C [26] kg/m^3
[27] Control	[28] 425.73	[29] -	[30] -	[31] 615.64	[32] 1182.65	[33] 0.45
[34] MK 5% & FA 10%	[35] 362.62 [36]	[37] 15.95 [38]	[39] 28.24 [40]	[41] 660 [42]	[43] 1267.65 [44]	[45] 0.41 [46]
[47] MK 10% & FA 10%	[48] 299.69 [49]	[50] 31.92 [51]	[52] 28.24 [53]	[54] 660 [55]	[56] 1267.65	[57] 0.41
[58] MK 15% & FA 10%	[59] 280.95 [60]	[61] 47.89 [62]	[63] 28.24 [64]	[65] 660 [66]	[67] 1267.65	[68] 0.41
[69] MK 20% & FA 10%	[70] 262.22	[71] 63.85 [72]	[73] 28.24 [74]	[75] 660 [76]	[77] 1267.65	[78] 0.41
[79] MK 25% & FA 10%	[80] 243.57 [81]	[82] 79.82 [83]	[84] 28.24 [85]	[86] 660 [87]	[88] 1267.65	[89] 0.41

III. EXPERIMENTAL PROGRAM

3.1 Casting of Specimens

The test program was considered the cast and testing of concrete specimens of cube (150 mm) and cylinder (150 x 300 mm). The specimens were cast M30 grade concrete using ordinary Portland cement, Natural River sand and the crushed stone of maximum size 12.5 mm. Each three numbers of specimens were made to take the average value. The specimens were demoulded after 24 hours. The specimens were allowed to the curing periods.

3.2 Testing of Specimen

Testing of specimens was shown in Fig 3.1. The Compressive Strength, Split Tensile Strength and Flexure Strength of test values were presented in Tables 3.6, 3.7 and 3.8.

3.2.1 Compressive strength: For each mix, totally nine number of cubes of size150mm were cast and tested using 200T capacity compression Testing Machine (CTM). The specimen was placed on the platform of the compression testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the compressive strength of corresponding specimen. .

3.2.2 Split Tensile Strength: For each mix, totally nine number of cylinders of size 300 x 600 mm were cast and tested using 100T capacity compression Testing Machine (CTM). The specimen was placed perpendicular to normal axis on the platform of the compression testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the tensile strength of corresponding specimen.

Fig. 3.1 Compression, Split Tensile and Flexural Strength Testing Set ups

3.2.3 Flexural Strength: For each mix, totally nine number of prism of size 100 x 100 x 500 mm were cast and tested using 5T capacity Flexural Testing Machine (FTM). The specimen was placed perpendicular to normal axis on the platform of the flexural testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the flexural strength of corresponding specimen.

IV. RESULTS AND DISCUSSION

The test results of concrete specimens were discussed as below:

4.1Compressive Strength: The compressive strength was compared to control specimen with various percentages of metakaolin and 10 % of constant fly ash. The compressive strength for MK 5% increases in 10.82%, when compared to control specimen. The compressive strength for MK 10%, 15% 20% and 25% increases in 29.75%, 55.16%, 72.14% and 28.43% respectively, when compared to control specimen. MK 25% decreases in 25.18%, when compared to MK20%. MK 20% increases in higher strength, when compared to all other mixes. The compressive strength and various mix concrete test values are presented in Table 4.1 and variation of compressive strength was shown in Fig.4.1.

Table 4.1 Compression Test Results

Specimens	Load in Tonne	Tensile Strength N/mm^2
Control	17	2.41
MK 5% Fly ash 10%	19.5	2.75
MK 10% Fly ash 10%	23	3.25
MK 15% Fly ash 10%	24	3.39
MK 20% Fly ash 10%	25	3.5
MK 25% Fly ash 10%	22	3.11

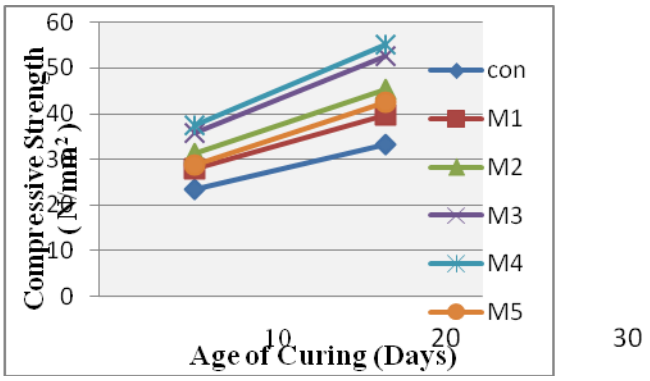

Fig.4.1 Variation of Compressive Strength

The split tensile strength for MK 5% increases in 14.51%, when compared to control specimen. The split tensile strength for MK 10%, 15% 20% and 25% increases in 34.85%, 40.66%, 45.33% and 29.05% respectively, when compared to control specimen. MK 25% decreases in 10.99%, when compared to MK20%. MK 20% increases in higher strength, when compared to all other mixes. The split tensile strength and various mix concrete test values are presented in Table 4.2 and variation of split tensile strength was shown in Fig.4.2.

Table 4.2 Split Tensile Test Results

Specimens	Load in Tonne	Compressive Strength N/mm^2
Control	76.5	34.08
MK 5% Fly ash 10%	85	37.77
MK 10% Fly ash 10%	99.5	44.22
MK 15% Fly ash 10%	119	52.88
MK 20% Fly ash 10%	132	58.66
MK 25% Fly ash 10%	98.5	43.77

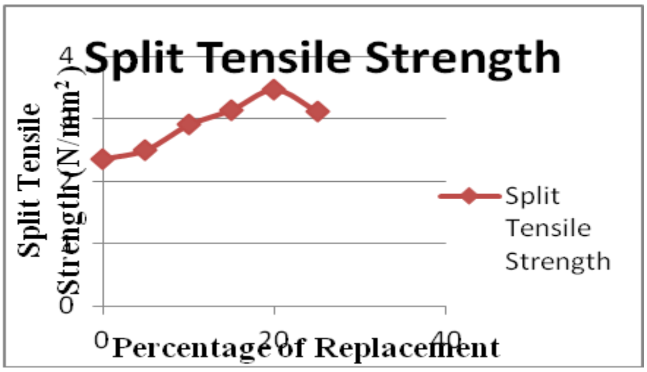

Fig.4.2 Variation of Split Tensile Strength

4.3 Flexural Strength: The flexural strength was compared to control specimen with various percentages of metakaolin and 10 % of constant fly ash. The flexural strength for MK 5% increases in 4.80%, when compared to control specimen. The flexural strength for MK 10%, 15% 20% and 25% increases in 9.61%, 12.81%, 19.93% and 16.19% respectively, when compared to control specimen. MK 25% decreases in 3.00%, when compared to MK20%. MK 20% increases in higher strength, when compared to all other mixes. The flexural strength and various mix concrete test values are presented in Table 4.3 and variation of flexural strength was shown in Fig.4.3.

Table 4.3 Flexural Strength Test Results

Specimens	Flexural Strength N/mm^2
Control	5.62
MK 5% Fly ash 10%	5.89
MK 10% Fly ash 10%	6.16
MK 15% Fly ash 10%	6.34
MK 20% Fly ash 10%	6.73
MK 25% Fly ash 10%	6.53

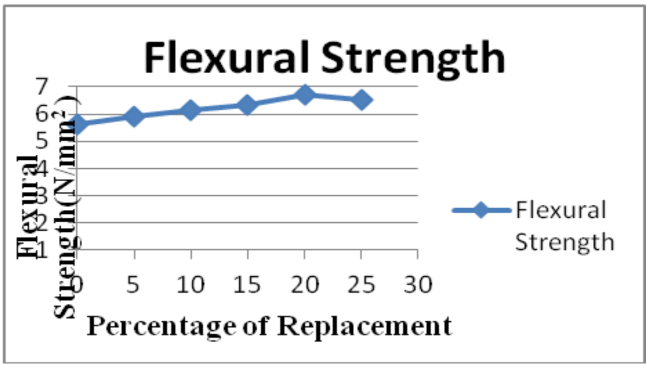

Fig.4.3 Variation of Flexural Strength

V. CONCLUSIONS

From the present investigation on the effect of partial replacement of cement with metakaolin in concrete, the following conclusions were drawn:

- The strength of all metakaolin concrete mixes over shoot the strength of OPC.
- 20% cement replacement by metakaolin is superior to all other mixes.
- The increase in metakaolin content improves the compressive strength and split tensile strength up to 20% cement replacement.
- The results encourage the use of metakaolin, as pozzolanic material for partial replacement in producing high strength concrete.

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