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Analyse the Mechanical Properties of Metakaolin Using As a Partial Replacement of Cement in Concrete

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Abstract-- Cement concrete is the most extensively used construction material. Maintenance and repair of concrete structures is a growing problem involving significant expenditure. As a result carried out worldwide, it has been made possible to process the material to satisfy more stringent performance requirements, especially long–term durability. HPC is the latest development in concrete. It has become very popular and is being used in many prestigious projects such as Nuclear power projects, flyovers multi-storeyed buildings. When using HPC, the addition of supplementary materials in cement has dramatically increased along with the development of concrete industry, due to the consideration of cost saving, energy saving, environmental concerns both in terms of damage caused by the extraction of raw materials and carbon dioxide emission during cement manufacture have brought pressures to reduce cement consumption.

Metakaolin looks to be a promising supplementary cementitious material for high performance concrete. Properties of concrete with metakaolin are mostly preferred additives in high performance concrete. A possible lower cost, due to large availability in our country itself may be advantages to metakaolin usage in HPC. The substitution proportion of metakaolin is to be used was 5%, 10%, 15%, 20% by the weight of cement. To make cubes and cylinders and to determine the strength and durability of concrete of it. The results indicate that the replacing mix up to till last percent has to noted and effect on strength in comparing with mixer without metakaolin.

Keywords: Metakaolin, Concrete mix, Compressive strength, Split Tensile strength, Flexural strength.

I. Introduction

Metakaolin is a pozzolanic additive/product which can provide many specific features. Metakaolin is available in many different varieties and qualities. The purity will define the binding capacity or free lime. Some of them also provide special reactivity. Metakaolin is a valuable admixture for concrete and or cement applications. Usually 8% - 20% (by weight) of Portland cement is replaced by metakaolin. Such a concrete exhibits favourable engineering properties. The pozzolanic reaction starts soon and continues between 7 to 28 days. For the preliminary investigation, metakaolin and cement was subjected to physical and chemical analyses to determine whether they are in compliance with the standard use. The experimental program was designed to investigate metakaolin as a partial replacement with cement was done at 5%, 10%, 15% , 20%. The specimen was casted with M60 grade of concrete with different replacement levels of metakaolin.

II. Literature Review

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/mm2 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 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.

III. Material Used

3.1 Cement: OPC of 53 Grade confirming to IS:12269-1987 was used in the investigation. The specific gravity of cement was 3.10

3.2 Coarse Aggregate: Crushed stone metal with a maximum size of 20 mm from a local source having the specific gravity of 2.7 conforming IS383-1970 was used.

3.3 Fine Aggregate: Locally available river sand passing through 4.75mm IS sieve conforming to grading zone-II of IS383-1970 was used. The specific gravity of fine aggregate was 2.54.

3.4 Metakaolin

Metakaolin is not a by-product. I t is obtained by the calcinations of pure or refined Kaolinite clay at a temperature between 650^0 C and 850^0 C, followed by grinding to achieve a finesse of 700-900 m^2/kg. It is a high quality pozzolonic material, which is blended with cement in order to improve the durability of concrete. When used in concrete it will fill the void space between cement particles resulting in a more impermeable concrete.

Metakaolin is a relatively new material in the concrete industry, is effective in increasing strength, reducing sulphate attack and improving air-void network. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability. The formation and properties of Metakaolin are shown in below. The specimen kept immerse in water for 7 and 28days.The chemical content of metakaolin presented in Table 1.

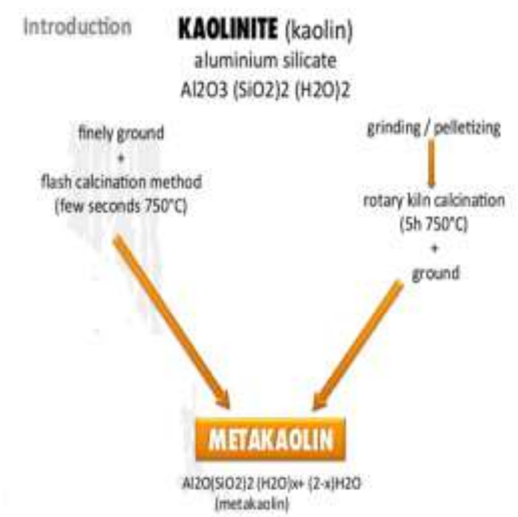

Fig.1 Formation of Matakaolin

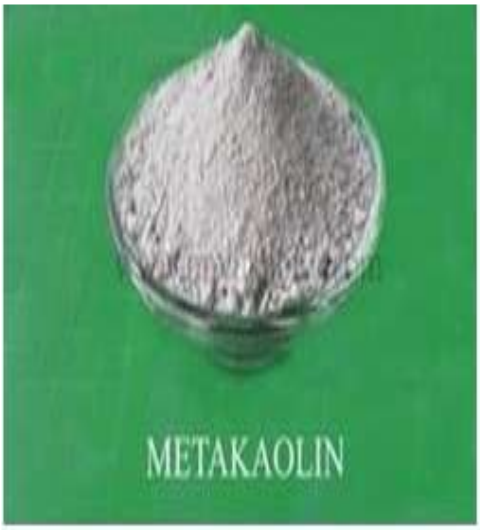

Fig.2 Appearance of Metakaolin

Table 1 Property of Cement and Metakaolin

Chemical composition	Cement %	Metakaolin %
Silica (SiO_2)	34	54.3
Alumina Al_2O_3	5.5	38.3
Calcium oxide CaO	63	0.39
Ferric oxide Calcium oxide (Fe_2O_3)	4.4	4.28
Magnesium oxide (MgO)	1.26	0.08
Potassium oxide (K_2O)	0.48	0.50
Sulphuric anhydride (SO_4)	1.92	0.22
LOI	1.3	0.68
Specific gravity	3.15	2.5
Physical Form	Fine Powder	Powder
Colour	Grey	Off white

3.5 Super Plasticizer

Poly-carboxylate Ether Super plasticizer obtained from Chemcon tech SYS was used .It conforms to IS 9103 – 1999 and its specific gravity of 1.2.

3.6 Water

Fresh portable water is free from concentration of acid and organic substance is used for mixing the concrete and curing.

3.7 Mix Proportions

Trial mixtures were prepared to obtain target strength more than 60 MPa for the control mixture at 28 days and the w/b ratio for all the mixtures were kept at 0.32. The details of the mixture (MK0, MK5, MK10, and MK15,20) were employed to examine the influence of low w/b ratio on concretes containing MK on the mechanical and durability properties. The slump of fresh concrete found as 105 to 110mm. The mix proportions for conventional and volume based partial replacement OPC by Metakaolin presented in Table 2.

Table 2 Mix proportion of concrete

Ingredients	OPC 0%MK	5% MK	10% MK	15% MK	20% MK
Cement	510	485	460	435	410
Metakaolin	0	25	50	75	100
Fine Aggregates	806	806	806	806	806
Course Agg. 20mm to 4.75mm	972	972	972	972	972
Superplasticizer	3.0	3.25	3.6	3.8	4.0
Slump (mm)	120	110	115	105	100
Water	162	162	162	162	162

IV. EXPERIMENTAL PROGRAM

4.1 Casting of Specimens

The test program considered the cast and testing of concrete specimens of cube (150mm) and (150x300mm). The specimen was cast M60 grade concrete using OPC, Natural River sand and crushed stone (20mm 4.75mm) with Metakaolin. Each three numbers of specimens made to take the average value. The Specimens demoulded after 24hrs.The specimens were allowed to the curing periods.

4.2 Testing of Specimen

Testing of specimen was shown in Fig 3.1. The Compressive Strength, Split Tensile Strength and Flexure Strength of test values were presented in table 3, 4, and 5.

4.2.1 Compressive Strength

For each mix, twenty four number of cubes of size 150mm were cast (7days and 28days) and tested using Compression Testing Machine (CTM). The specimen placed on the platform of the CTM. The load applied gradually until the failure stage. The ultimate load noted and calculated the compressive strength of corresponding specimen.

4.2.2 Split Tensile Strength

For each mix, twelve numbers of cylinders of size 300x600mm cast and tested in CTM. The specimen placed perpendicular to normal axis on the platform of the CTM. The load applied gradually until the failure stage.

4.3.3 Flexural Strength

For each mix, totally twelve number of prism of size 100x100x500mm cast and tested in Flexural Testing Machine (FTM). The specimen of prism placed horizontally on the platform of the FTM. The ultimate load noted and calculated the flexural strength of corresponding specimen.

V. RESULTS AND DISCUSSION

The test results of concrete specimen discussed as below:

5.1 Compressive Strength

The Compressive Strength compared to control specimen with various percentages of Metakaolin. Compressive Strength results of specimens presented in Table 3. The seven day Compressive Strength varied between 45 and 55MPa. The 28 day strength varied between 61 and 73MPa. The 20% replacement MK mixture exhibited lower strengths comparatively than the other MK percentages. All the concrete s including the control achieved their target strength of 60MPa at 28 days and all the concretes achieved strength of more than 70MPa. Fig.3 presents the relation between Compressive Strength and MK percentages at 7 and 28 days. The highest value for the MK15 mixtures achieving strength of 72.7MPa at 28days is given below. This clearly shows the replacement level of 15% was the optimum Compressive Strength is concerned.

After 28 days the compressive strength for MK 5% increases in 4.36%, [(64.6/61.9x100)-100] when compared to control specimen. The compressive strength for 10%, 15% and 20% increases in 13.73%, 17.45% and 12.44% respectively. MK 15% increases in higher strength, when compared to all other mixes. But MK 20% decreases in 4.26% from MK 15%. So MK 15% is the best proportion for add in cement.

Table 3 Compressive Strength in MPa

Age of test	Pure OPC			5% Metakaoline			10% Metakaoline			15% Metakaoline			20% Metakaoline		
7 day cube strength	43.9	47.4	44.0	50.2	51.5	50.9	52.9	52.3	50.4	52.8	56.8	54.9	52.1	51.9	50.2
	45.1			50.9			51.9			54.8			51.4		
28 day cube strength	63.1	61.1	61.6	63.5	67.5	62.6	67.5	72.4	71.4	72.8	71.1	74.2	67.2	70.2	71.6
	61.9			64.6			70.4			**72.7**			69.6		
% of Increasing from MK0%	-			4.36%			13.73%			**17.45%**			12.44%		

Fig.3 Compression testing

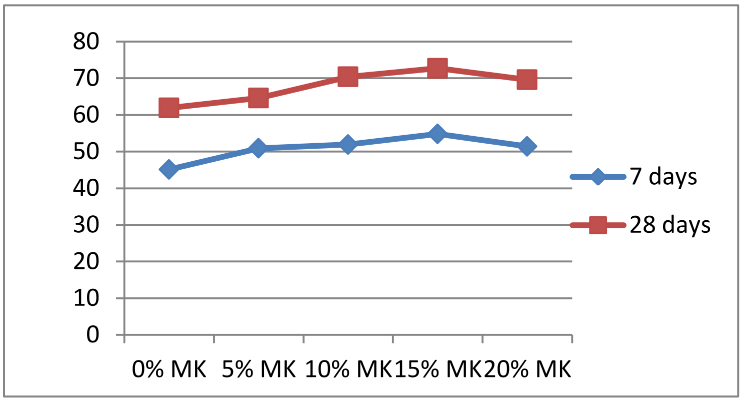

Fig. 4. Variation of Compressive Strength

5.2 Split Tensile Strength

From the results Split Tensile Strength also exhibited the highest strength at MK15 mixture. The Split Tensile strength for MK 5% increases in 8.82%, when compared to control specimen. The Split Tensile strength for MK 10%, 15% and 20% increases in 14.70%, 20.56% and 11.76% respectively. MK 15% increases in higher strength, when compared to all other mixes. But MK 20% decreases in 7.31% from MK15%. So MK 15% is the best proportion for add in cement. The split tensile strength and various mix concrete test values are presents in Table 4 and variation of split tensile strength shown in Fig.4

Table 4 Split Tensile Strength in Mpa

Age of test	0% Metakaoline			5% Metakaoline			10% Metakaoline			15% Metakaoline			20% Metakaoline		
28 day split tensile strength	3.3	3.2	3.6	3.5	3.8	3.7	4.0	3.7	4.0	4.0	4.3	4.2	3.9	3.6	4.0
	3.4			3.7			3.9			4.1			3.8		
% of Increasing from MK0%	-			8.82%			14.7%			20.56%			11.76%		

Fig. 3 Split Tensile testing

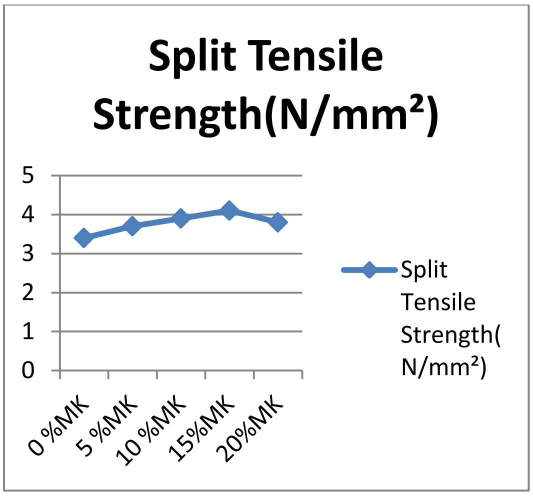

Fig. 4. Variation of Split Tensile Strength

4.3 Flexural Strength

The Flexural strength compared to control specimen with various percentages of Metakaolin. When compared to control specimen the Flexural strength for MK5% increases 4.76% . The Flexural strength for MK 10%, 15% and 20% increases 11.11%, 14.28% and 7.94% respectively. MK 15% gave high flexural strength. But 20% of MK decreases in 5.55% from MK15%. So MK 15% is the best proportion for add in cement. The Flexural strength and various mix concrete test values are presents in Table 5 and variation of Flexural strength shown in Fig.6.

Table 5 Flexural Strength in MPa

Age of test	**Pure OPC**			**5% Metakaoline**			**10% Metakaoline**			**15% Metakaoline**			**20% Metakaoline**		
28 days Flexural Strength	6.4	5.9	6.6	6.5	6.6	6.7	6.8	7.2	7.2	7.0	7.2	7.3	6.7	6.9	6.8
	6.3			6.6			7.0			7.2			6.8		
% of Increasing from MK0%	-			6.6%			11.11%			7.2%			6.8%		

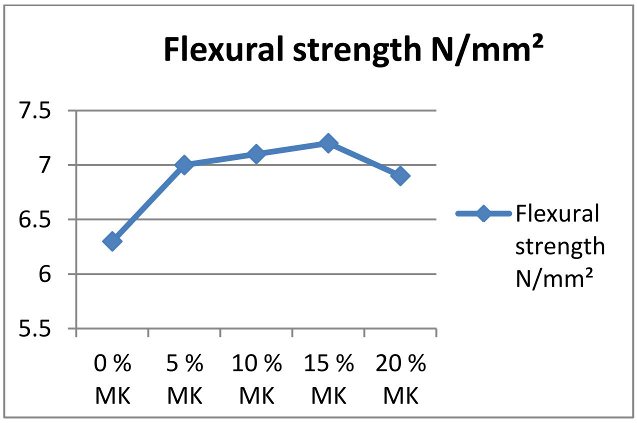

Fig.5 Flexural Strength testing

Fig. 6. Variation of Flexural Strength Strength

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.
- 15% 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 15% cement replacement.
- The results encourage the use of Metakaolin, as a pozzolanic material for partial replacement in producing high performance concrete.

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