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Changes in properties of cement using partial use of Metakaolin and Silica Fume

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ABSTRACT

Due to infrastructure development in the developing countries, consumption of concrete is very high. The consumption of cement is also very high to meet the requirements. So there is a need to look after the supplementary / alternative materials for the cement, fine aggregate and coarse aggregate. The present work aims to look after the supplementary materials in the concrete. In this paper, supplementary materials like metakaolin has been used in the concrete.The present study includes the effect of partial replacement of cement with metakaolin by various percentages(0%, 10%, 15%, 20%, 25% and 30%) on the properties of high strength concrete,

The other objective of this paper is to determine the isolated effect of silica fume on tensile, compressive and flexure strengths on high strength lightweight concrete. Many experiments were carried out by replacing cement with different percentages of silica fume at different constant water-binder ratio keeping other mix design variables constant. The silica fume was replaced by 0%, 5%, 10%, 15%, 20% and 25% for a water-binder ratios ranging from 0.26 to 0.42. For all mixes, split tensile, compressive and flexure strengths were determined at 28 days.

KEYWORDS: Metakaolin, High Performance Concrete (HPC),Supplementary cementing materials, Cement, Concrete,Silica fume, Lightweight.

INTRODUCTION

Conventional concrete is oftenproduced with four components namely, a) cement and b) Water, together they act as binder. c) Thecrushed or uncrushed stone and d) natural sand orstone dust. In addition to the above ingredients oneor two additional chemicals are also added to therecipe of concrete in order to enhance someproperties.The utilization of supplementary materials like metakalio and silica fly in concrete can partially reduce the consumption of

Portland cement, which, in turn, can lessen construction costs, providing materials suppliers, contractors and engineers with substantial advantages.

The High Performance Concrete isconcrete which ensures long-time durability in structures exposed to aggressive environments. Durability of concrete is its ability to resist weathering action, chemical attack, abrasion and allother deterioration processes. Weathering includesenvironmental effects such as exposure to cycles ofwetting and drying, heating and cooling, as alsofreezing and thawing. Chemical deteriorationprocess includes acid attack, expansive chemicalattack due to moisture and chloride ingress

1. METAKAOLIN

Metakaolin is one of the supplementary cementetiousmaterials (SCM). Metakaolin is a high quality pozzolanic material, which is blended with Portland cement in order to improve the strength and durability of concrete and mortars.

The raw material in the manufacture of Metakaolin is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Metakaolin is neither the by-product of an industrial process nor is it entirely natural. It is derived from naturally occurring mineral and is manufactured specially for cementing applications.

Metakaolin isproduced under carefully controlled conditions to refine its color, remove inert impurities,and tailor particle size such, a much high degree of purity and pozzolanic reactivity can beobtained. The chemical equations describing this process is $Al_2O_3.2SiO_2.2H_2O = Al_2O_3.2SiO_2 + 2H_2O$ (g).

Table :1.1 Properties of Metakaolin

Property	**Results**
Specific Gravity	2.54
Accelerated pozzolanic active index,% of control	89
Residue on 45µsieve, %	1.31
Chemical analysis, % Loss on ignition Silica (SiO2) Iron oxide (Fe2O3) Aluminum (Al2O3) Calcium oxide (CaO) Magnesium Oxide (MgO)	0.70 52.24 0.60 43.18 1.03 0.61

The uses of metakaolin for various types of concrete are listed below:

- Glass fiber-reinforced concrete
- Fiber cement and fibrocement products
- High-strength, high-performance, and lightweight concrete

- Precast concrete for architectural, civil, industrial, and structural purposes
- Pool plasters, repair material, mortars and stuccos

Metakaolin removes chemically reactive calcium hydroxide from the hardened concrete.High reactivity metakaolin, which is a relatively newer material in the concrete industry, is effective in increasing the compressive strength, reducing the sulfate attack and improving air-void network.Metakaolin is a white pozzolan made by heating kaolin clay to a temperature of 6000C-8000Crange; kaolinite becomes metakaolin, with a two-dimensional order in crystal structure.

Mineral admixtures such as fly ash, rice husk ash, metakaolin, silica fume etc are more commonly used in the development of HPC mixes. They help in obtaining both higher performance and economy. These materials increase the long term performance of the HPC through reduced permeability.

This study proposes to analyze the mechanical strength as well as the durability by means of capillary absorption test, water permeability and gas permeability of concrete made with a local metakaolin.

Table 1.2 Physical properties of MK

Specific Gravity	2.40 to 2.60
Physical Form	Powder
Color	Off white, Grey to Buff
Specific Surface	8– 15 m2 /g.

Table 1.3 Chemical properties of MK

SiO2	51-53 %	CaO	< 0.20%
Al2O3	42-44 %	MgO	< 0.10%
Fe2O3	< 2.20%	Na2O	< 0.05%
TiO2	< 3.0%	K2O	< 0.40%
SO4	< 0.5%	L.O.I.	< 0.50%
P2O5	< 0.2 %		

RESULTS AND ANALYSES

The tests were carried out to obtain compressive strength, split tensile strength, flexural strength and stress-strain curve of M80 grade concrete. The specimens are tested for 28 days for 0%, 10%, 15%, 20%, 25% and 30% replacement of MK for compressive strength and the specimens are tested for 28 days for 0% and 10% replacement of MK for flexural strength, stress-strain curve, split tensile strength.

Effect of MK on the Compressive Strength of Concrete: MK plays an important role in increasing the compressive strength of concrete especially at 10% of MK where a compressive strength of 41.5 MPa at 60 days is achieved compared to 34.50 for concrete mix without Mk (MK0). It is observed that at 10% replacement of cement with MK, concrete

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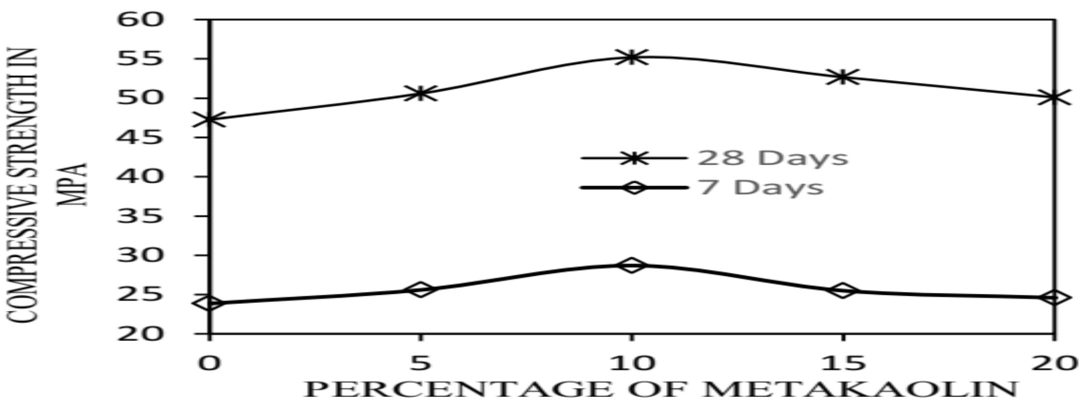
attains a maximum compressive strength when exposed to 0.5%HCl compared to 1% HCL at the age of 28 days. So as the percentage of HCL concentration increases, the strength decreases.

Table 5.1.1: Percentage decrease in compressive strength test results of HPC for 0.3 W/B ratio

% replace-ment of cement by Metakaolin	28 days compr-essive strength (ref.mix)	30 days compr-essive strength	% decrease in compr-essive strength	60 days compr-essive strength	% decrease in compr-essive strength	90 days compr-essive strength	% decrease in compr-essive strength
0	83.42	76.75	7.99	71.73	14.01	65.91	20.99
10	94.22	87.64	6.98	84.31	10.52	78.22	16.98
20	82.13	76.86	6.41	74.31	09.52	68.98	16.01
30	79.33	74.53	6.05	72.53	08.57	67.38	15.06



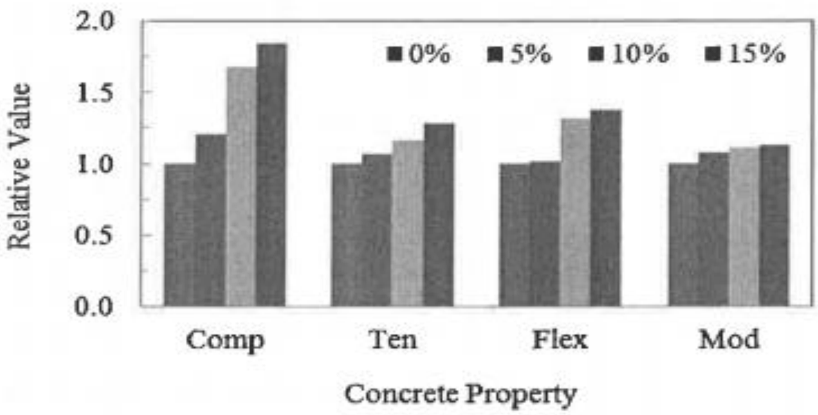


Figure 5: Effectiveness of MK on 28-day properties of concrete (adapted from [14])

Three basic factors affect the contribution of MK to the compressive strength of concrete when it partially replaces cement in concrete. These are *the filler effect*, accelerating the

hydration of CEM I and the pozzolanic reaction of MK with CH. The effect of filler results in a more efficient packaging of the paste is immediate, the acceleration of the hydration of

CEM I has maximum impact within the first 24 hours and the pozzolanic reaction provides the largest contribution to the compressive strength between 7 and 14 days

Table 2: Effect of metakaolin content on tensile and flexural strength of concrete [14]

Age (days)	Property	Control	Cement replacement with MK		
			5%	10%	15%
3	Compressive Strength	27.9 MPa	1.29	1.40	1.51
28		37.8 MPa	1.21	1.68	1.84
60		58.0 MPa	1.08	1.15	1.34
28	Tensile Strength	3.35 MPa	1.07	1.16	1.28
28	Flexural Strength	4.65 MPa	1.02	1.32	1.38
80		5.70 MPa	1.02	1.13	1.24
3	Modulus of Elasticity	24.1 GPa	1.06	1.05	1.09
28		30.0 GPa	1.08	1.11	1.13
60		30.4 GPa	1.09	1.11	1.14

Effect of MK on the Penetration of Water: One of the main factors of the durability of concrete is permeability. Concrete with lower permeability provides better resistance against chemical attack, because when water penetrates concrete along with soluble salts it causes corrosion of steel. We note that the incorporation of metakaolin has a very positive effect on the permeability of water under pressure. Mixes with 10% MK have the best results with a decrease of water permeability of about 25%. However, the mix with 15% MK decreases the permeability by about 15%.also The incorporation of MK in concrete increases the penetration resistance of chloride ions

2. Silica Fume (SF)

Silica fume is a byproduct resulting from the reduction of high purity quartz with coal, in electric arc furnaces in the production of silicon and Ferro-silicon alloys. The material, which contains more than 80% of silica in non-crystalline state in the form of extremely fine particles, is highly pozzolanic .It is also collected as a byproduct in the production of other silicon alloys such as Ferro chromium, Ferro magnesium and Calcium Silicon.

Table 2.1 The properties of the silica used are as follows:

Property	**Value**
Specific gravity Fineness by wet	1.84
Sieving on 45 µ sieve	5.04
Lime reactivity	2.34 Mpa
Compressive strength	14.35 Mpa (7 days)
Initial setting time	40 minutes
Final setting time	143 minutes
Loss of ignition	10%
Soundness	11.4%

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Effect of silica on Compressive Strength: The isolated effect of SF increases the compressive strength as shown in Fig. 3. This Fig. shows the variation ofcompressive strength with SF replacement percentages where the compressive strength values at different w/c ratios have been plotted for the five SF replacement percentages in addition to the control mix (0% SF). The percentages of gaining strength with respect to the control mix for w/c 0.26, 0.3, 0.34, 0.38 and 0.42 at 5%, 10%, 15%, 20% and 25% SF replacements are 15.8%, 29.1%, 35.5%, 31.5% and 31.25%, respectively

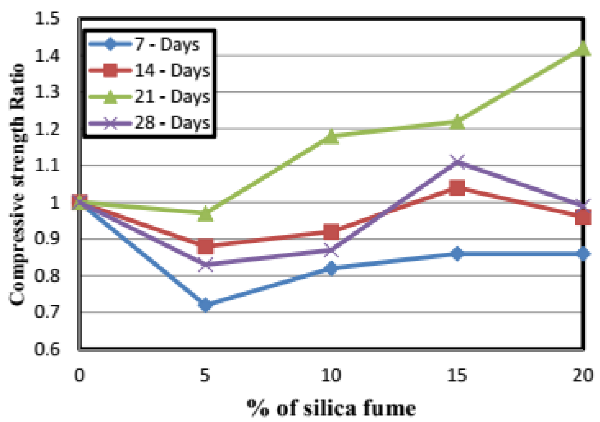

Figure.1. Compressive strength ratio vs percentage replacement of cement by silica fume for 1:6 mix

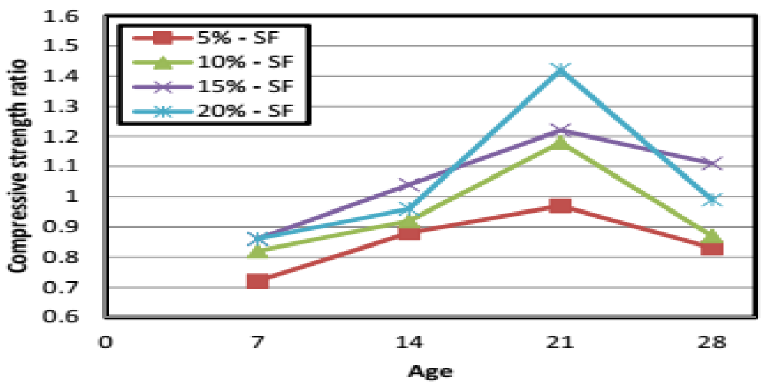

Figure.4. Compressive strength ratio vs Age for 1:6 mix

The results indicate that the highest compressive strength for w/c 0.26 is 61.75 MPa at 15% SF replacement. For w/c 0.3 and 0.34; the highest is 56.23 and 52 MPa, respectively, at 20% SF replacement. While, for w/c 0.38 and 0.42; the highest is 46.15 and 40.95 MPa, respectively, at 25% SF replacement.

Effect ofSilicaon Split Tensile Strength: There is variation of split tensile strength with the SF replacement percentages at different w/c ratios. The trend in the strength gain is almost similar to that in compressive strength. The percentages of gaining strength with respect to the control mix for w/c 0.26, 0.3, 0.34, 0.38 and 0.42 at 5%, 10%, 15%, 20% 1nd 25% SF replacements are 26.9%, 22.29%, 28.43%, 27.7% and 39.07%, respectively.

The results show that the optimum SF replacement percentage for obtaining maximum 28 day split tensile strength of lightweight high strength concrete is almost a unique where it is noted 15% for w/c 0.26 and 0.30, and 20% for w/c 0.34, 0.38 and 0.42

CONCLUSIONS

Based on the experimental investigations carried out, the following conclusions are made.

- MK has been shown to impart benefits in increasing both early and long term mechanical properties of cement paste mortar and concrete. With regards to permeability, MK modifies the pore structure of cement mortar and concrete with significant reduction in permeability and resistance to transport of water and harmful ions. MK replacement of cement has shown to impart effective resistance against sulfate attack and to some extend against chemical ingression. A replacement level of 10 to 15% MK has shown very good results in thisregards. Further, Inclusion of high reactive MK as partial replacement in optimal range isshown to control detrimental expansion due to ASR in concrete. However as a negative aspect, MK has also been shown to increase shrinkage and heat evolved during hydration, which can be detrimental and needs to be further researched and worked on.
- The isolated effect of SF increases the compressive, splitting tensile and flexure strengths. The highest increase has been found in the flexure strength. The trend in the strength gain due to SF replacement in compressive strength is almost similar to that in split tensile strength for lightweight high strength concrete.The optimum SF replacement percentages for obtaining maximum 28 day compressive and flexure strengths of lightweight high strength concrete ranges from 15% to 25% depending on the w/c ratio of the mix. The optimum percentage of SF replacement increases with the increase of w/c ratio. This percentage is almost a unique for tensile strength where it is noted 15% for w/c 0.26 and 0.30, and 20% for w/c 0.34, 0.38 and 0.42.

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