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## Silica Fume and Metakaolin as Supplementary Cementing Materials- A Review

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**ABSTRACT:** The replacement of cement by various mineral admixtures as supplementary cementing materials for concrete has gained a global attention in recent years. This replacement becomes efficient not only by increasing the strength and durability of the concrete but also reduces the usage of the ordinary cement thereby curtailing the environmental hazardous due to cement manufacturing industries. This paper reviews the work carried out on the use of silica fume (SF) and Metakaolin (MK) as supplementary cementing materials as a partial replacement for cement. The literature demonstrates that both SF and MK are effective and causes significant improvement in various properties of the concrete in both fresh and harden state.

**KEYWORDS:** Metakaolin, Silica Fume, Compressive Strength, Durability Properties.

### I. INTRODUCTION

Major of the construction company relies on the concrete. Cement is major constituent of concrete. The annual global production of ordinary portland cement is about 3 Gt. Cement becomes a dominant binder due to its versatility, durability, and its demand increases dramatically. Even though it is a vital material, its production directly affects the environment by releasing 0.87t of carbon dioxide for every tonne of cement produced. (2) and this contribute 5% of manmade carbon dioxide emission(2). This leads to the introduction of various supplementary materials as an alternative for concrete. Most of these alternatives are either from waste material or by products in manufacturing of some other materials including fly ash left behind the coal combustion, ground granulated blast furnace slag from iron manufacturing industry and silica fume from ferrosilicon production. However these materials replace the cement partially to a maximum extends of 50%.

The main aim of introducing these materials in concrete is not only because of the environmental concern but also these materials plays an important part in hydration process during the concrete production. The ordinary portland cement during hydration produces 60%-70% of C-S-H gel, which is primarily important for the strength of the concrete and 20%-25% of CH (Portlandite) which is associated with poor durability and it has no importance other than lining the pores. The supplementary cementing materials react with this CH and thus converting into C-S-H gel, which in turn increases the strength of the concrete. Due to the pozzolanic property, the utilisation will increases in coming years. Use of MK and SF has gained much interest on removal of CH which is formed during the hydration of the cement.

### II. SOURCE AND ITS NATURE

Clay minerals are available abundant on earth crust. Kaolinitic clays on heat treatment between 600 and 800°C leads to the dehydroxylation of the crystalline structure to form Metakaolin (3). MK possess a good pozzolanic properties (3). MK can improve both mechanical and durability of concrete. The Penta-coordinated aluminium ions that are formed during the dehydroxylation process is responsible for the reactivity of MK (4) The silica fume (SF) is the by product in the ferrosilicon production. SF consists of silicon dioxide (SiO<sub>2</sub>) which is non crystalline. SF increases the bond between the gel and the aggregates (5) .SF is well known for its fineness so that it fills the pores present in the concrete. It is found to be effective in lowering the total porosity and finer pore size (6).

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## III. PORTLANDITE CONSUMPTION

M. Antoni et al (2012)(7) carried out a thermogravimetric analysis for characterization of pozzolanic reaction by concrete containing MK and limestone. Paste samples 40 mg of pieces were used for testing. The paste sample with 30% Metakaolin showed an effective reduction in the calcium hydroxide even as early as day 1. But the blend with 60% total replacement (40% MK and 20% of limestone) shows a stronger reduction in CH content. Even it shows a nearly complete consumption of CH after only 7 days.

Salim Barbhuiya et al (2015)(8) carried out an experimental investigation on hydration of concrete containing MK. The X-Ray diffraction technique was used to study the crystalline phases of concrete. The XRD patterns for 3 days and 28 days were collected and these patterns visualize that considerable increases in the amount of the CH after 28 days for the mix without MK but for the mix with MK after 28 days of curing it is observed that the rate of production of crystalline CH seems to be reducing as compared to the reference mix.

Hamdy El-Diadamony et al (2015)(8) carried out an experimental study on hydration and characteristic of Metakaolin pozzolanic cement pastes. Mixes were prepared with partial replacement of (5%, 10%, 15% and 20%) MK. XRD analysis was carried out at 3, 28 and 90 days to study the patterns of hydrated cement pastes. The patterns visualize that the intensities of portlandite were higher for OPC paste than that of Pozzolanic cement pastes with MK and this is due to the pozzolanic reaction of MK with CH. It was clear that the amount of CH decreases with increasing time of hydration.

Zengqi Zhang et al (9) experimentally studied the hydration and microstructures of concrete with SF (densified and raw). The amount of  $\text{Ca}(\text{OH})_2$  in the paste samples were determined by thermogravimetry. This test was carried on 3 and 90 days of curing. The data collected from the thermogravimetry shows that addition of silica fume decreases the content of CH. This is due to the reaction of SF with CH and thereby increasing the C-S-H gel.

J.I. Escalante-Garcia et al (2017)(10) studied the effects of four pozzolans on hydration and strength. Among the four pozzolans the addition of siliceous materials accelerates the hydration reaction and thereby producing C-S-H gel by pozzolanic reaction between CH and SF.

## IV. WORKABILITY

H. Paiva et al (2012) (11) studied the effect of MK on the fresh and hardened state concrete. The mixes were prepared with partial replacement of MK (10%, 20% and 30%) for cement. The water reducer admixture was also used. To assess the workability, the slump values of the mixes were determined by the Abrams cone. The observations visualize that water or water reducing admixture content should be increased for the mixes with increasing MK content to keep the workability.

According to the work of M. Antoni et al (2012) (7) suggest that it is necessary to use superplasticizer to adjust the workability. It is clear that, the addition of MK demands more water thereby to maintain the workability.

J.M Khatib (2008) (12) investigated the performance of the concrete containing MK at low water to binder ratio (0.3), to evaluate the workability the tests like slump cone, compaction factor and Vebe tests were conducted. The results showed that, all the mixes including the mix without MK exhibited very low workability. The slump values were less than 20mm. Vebe time was more than 24s and the compaction factor was less than 0.8. The results visualize that presence of MK reduces the workability, so one can understand that super plasticizers are required to maintain the workability, when MK is used in the concrete.

Vikas Srivastava et al (2014) (13) studied the effect on workability and compressive strength of OPC concrete partially replaced with SF. The mixes were prepared with an replacement (0%, 5%, 10%, 15%, 20% 25%, 30% and 35%) of SF. To study the workability the slump test was carried out. The results reported that the workability of the concrete increased with increases in SF content.

R. Duval et al (1998) (14) investigated the workability and compressive strength of the SF concrete at low water cement ratio with a naphthalene sulphonate superplasticizer to maintain constant slump. The silica fume content was replaced in order of 0, 10, 20 and 30% by mass for cement and the mix was made for different water cement ratios (0.25, 0.30, 0.35, 0.45). The superplasticizer dose was calculated by "Grout Method". The superplasticizer requirement for 10% replacement of SF was less compared to that of 0% SF concrete. The results concluded that concretes with

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W/C ratios varying from 0.25 to 0.45, the superplasticizer dosage were less for 10% sf and then it increases with increase in SF content. It is understood that the slump loss of SF concretes increases according to the percentage of silica fume in case of low W/C ratio of 0.25, but for higher ratios (0.35), the loss is less important and decreases with the SF content.

## V. COMPRESSIVE STRENGTH

Several experimental studies were carried out to evaluate the compressive strength of the concrete containing MK and SF. J.M. Khatib (2007) (12) reported that density of the concrete slightly increases with increasing amount of MK content. Relative strength at different curing times was plotted for MK concrete. Beyond one day curing, the mixes with MK seems to show higher relative strength and it was maximum at 15% of MK replacement at low water to binder ratio of 0.3. The maximum contribution of MK to strength occurs at 14 days of curing.

H. Paiva et al (2012)(11) reported that strength of the concrete increased even upto 30% replacement of cement with MK. Salim Barbhuiya (2015) (8) studied the compressive strength of the concrete containing MK at two different water to binder ratio 0.5 and 0.6. It is observed that, there was a slight increase in the strength with increases in the MK content. However the strength was more remarkable up to 10% replacement.

Vikas Srivastava et al (2014) (13) reported that 18.18% increase in the compressive strength of the concrete with 5% of SF. R. Duval et al (1998) (14) reported that the increase of the compressive strength of SF concretes depends much more on the decrease of the water/cementitious materials ratio than on the replacement of silica fume with cement. It is observed that there is an increase in the compressive strength of with increase in SF content up to 20%. However the maximum increase was observed at 10 -15% of SF replacement. The gain in strength compared to reference concrete remains less than 15%.

C.S Poon et al (2005) (6) compared the strength of concrete with MK and SF. The results show that strength of concrete with MK is superior to that with SF. The 10% replacement of MK resulted in the high strength gain over the control concrete.

ErhanGuneysi et al (2012) (1) investigated the strength of SF and MK concretes for two different water to cement ratio of 0.25 and 0.35. It is noted that for 0.35 water to cement ratio, the concrete with MK possessed higher compressive strength. However the strength of the concrete with SF and MK produced at 0.25 water to cement ratio, followed a close trend.

## VI. DURABILITY PROPERTIES

Ahmed tafraoui et al.(2016) (15) studied the durability performance of ultra high performance concrete containing the silica fume instead of metakolin and compared the results with their previous article in which metakolin is used in the formulation of the UHPC the replacements of admixtures where 25% of cement the following tests like porosity accessible to water, permeability to oxygen, diffusion and migration of chloride ions, absorption of water by capillary, test of accelerated carbonation and leaching with ammonium nitrate carried out to study the durability properties. Test results conclude that UHPC presents excellent properties in penetration resistance to various aggressive agents on comparison of UHPC with both silica fume and metakolin are similar but it has been shown that it was perfectly possible to carry out UHPC by using metakolin.

Poon C.S et al. (2006) (6) experimentally compared the both mechanical and durability properties of high performance metakolin and silica fume concretes to their micro structures characteristics the tests were carried out at two different water binder ratios (0.30&0.50) with replacement of metakolin (5%, 10%, 20%) and silica fume (5%&10%) chloride penetration tests were carried out and test results conclude that both metakolin and silica fume showed lower total charges passed than the control but at the water binder ratio of 0.3 10% metakolin replacement showed the best performance and at water binder ratio 0.5 the concrete with 20% replacement was the best

Erhanguneyisi et al. (2012) (1) investigated the effectiveness metakolin and silica fume on the chemical properties shrinkage and permeability related to durability of high performance concrete. The experiment were carried out at two different water cement ratios (0.25&0.35). Replacement were of 5%&15% of both admixtures gas permeability and water sorptivity tests were carried out and the test results suggest that increasing the amount of metakolin and silica

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fume resulted in sharp decreases in apparent gas permeability of concretes for both water cement ratio the maximum reductions were of 52% for metakolin and 61% for silica fume .the water sorptivity values was similar to gas permeability test results however the magnitudes of the reduction level was 30% and 28% for 15% replacement of metakolin and 15% of silica fume respectively.

Efstratios G. Badogiannis et al. (2015) (16) experimentally studied the durability of self compacting concrete incorporating metakolin .the tests like open porosity , sorptivity , water permeability , gas permeability, chloride penetrability were carried out and the results shows that low porosities were measured for higher metakolin content and the sportivity is inversely correlated to the replacement level with linear equations. The metakaolin SCC possess lower gas permeability compared to the reference concrete.

Assem A.A. Hassan et al.(2012) (17) carried out a comparative studies on the effect of cement replacement with both metakaolin and silica fume on the durability of self consolidating concrete the durability performance of scc concrete was evaluated based on results of drying shrinkage freezing and thawing ,salt scaling and rapid chloride test results conclude that addition of metakolin increase the viscosity ,passing ability and decrease the drying shrinkage and exhibited lower chloride permeability values .on comparison 20% replacement metakolin was form to be optimum overall .

## VII.CONCLUSION

The utilization of the industrial by product and other natural minerals as supplementary cementitious materials has been investigated widely for recent years. The work reviewed demonstrates that both MK and SF is an effective supplementary cementitious materials and these materials are effective in consumption of Portlandite and helps in early strength and has considerable effect in long term strength. Both SF and MK helps in filling the pore and thereby reducing pore structures in cement paste. The cost and environmental impact of the both MK and SF is comparatively less compared to OPC. Wider realisation of the benefits of MK and SF in concrete will lead to greater demands and this will leads to cost effectiveness and reduces the environmental impacts due to cement industry

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