A Review on Use of Metakaolin and OP Concrete

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Abstract: **Concrete is the most commonly used material for construction. The worldwide production of cement has greatly increased since 1990.Production of cement results in a lot of environmental pollution as it involves the emission of CO_2 gas. Supplementary cementations materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture. These supplementary materials may be naturally occurring, manufactured or man- made waste. Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time. Metakaolin is a dehydroxylated aluminium silicate. It is an amorphous non crystallized material, constituted of lamellar particles. From the recent research works using Metakaolin, it is evident that it is a very effective pozzolanic material and it effectively enhances the strength parameters of concrete. This paper reviews the use of metakaolin as supplementary cementitious material in concrete. A detailed literature survey is carried out and presented here.**

***Keywords*: Metakaolin, Supplementary cementitious material, Portland cement, Compressive strength.**

1. INTRODUCTION

The demand for Portland cement is increasing dramatically in developing countries. Portland cement production is one of the major reasons for CO_2 emissions into atmosphere. It is due to the use of fossil fuels, including the fuels required to generate electricity during cement manufacturing process. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with $Ca(OH)_2$ one of the by-products of hydration reaction of cement and results in additional C-S-H gel which results in increased strength. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. To obtain an adequate thermal activation, the temperature range should be established between 600 to 750ºC.Metakaolin is used in oil well cementing to improve the compressive and flexural strength of the hardened cement. Metakaolin also reduces the hardened cement permeability to liquids and gases. Hence by partially replacing Portland cement with Metakaolin not only reduces carbon dioxide emissions but also increases the service life of buildings.

Chemical formula of Metakaolin is
Al2O3·2SiO2·2H2O.

Calcium hydroxide is one of the by-products of hydration reaction of cement. When cement is partially replaced with Metakaolin, it reacts with calcium hydroxide and results in extra C-S-H gel. C-S-H gel is the sole cause for strength development in cement and cement based concrete. The chemical reaction is given below

Cement + Water = C-S-H gel + Ca (OH)2
Ca (OH)2 + Metakaolin = C-S-H gel

2. REVIEW OF LITERATURE

Sabir.B.B et al (2001) 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 (2002) 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. The incorporation 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.

Badogiannis.E et al (2004) evaluated the effect of Metakaolin on concrete. Eight mix proportions were used to produce high-performance concrete, where Metakaolin replaced either cement or sand of 10% or 20% by weight of the control cement content. The strength development of Metakaolin concrete was evaluated using the efficiency factor (k value). With regard tstrength development the poor Greek Metakaolin and commercially obtained Metakaolin yielded the same results. The replacement with cement gave better results than that of sand. When Metakaolin replaced cement, its positive effect on concrete strength generally started after 2 days where as in case of sand it started only after 90 days. Both Metakaolin exhibited very high k-values (close to 3.0 at 28 days) and are characterized ashighly reactive pozzolanic materials that can lead to concrete production with excellent performance.

Justice.J.M et al (2005) 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 great 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 (2005) 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 (2008)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.

Jiping Bai and Albinas Gailius (2009)developed statistical models for predicting the consistency of concrete incorporating Portland cement, Fly ash and Metakaolin from the experimental results of standard consistency tests. The effect of variations of pozzolanic replacement materials including Fly ash and Metakaolin replacement levels up to 40% and 50% respectively were tried. Consistency parameters were found out from the best fit models. Values of consistency were calculated by the proposed models and gave a good agreement with observed experimental data. It indicated that the models were reliable, accurate and can be used in practice to predict the consistency of Portland cement-Fly ash-Metakaolin blends.

Eva Vejmelkova et al (2010)experimentally studied a set of parameters of high performance concrete (HPC) with metakaolin including basic physical characteristics such as mechanical properties, fracture-mechanical properties, durability characteristics, hydraulic, thermal properties and chloride binding characteristics. The experimental results showed that the replacement of Portland cement by 10% Metakaolin as an optimal amount leads in most cases either to improvements or at least does not significantly impair substantial properties of the analyzed HPC. Basic physical properties and heat transport and storage properties are very similar to common HPC, mechanical and fracture-mechanical properties were improved, water- and water vapor transport parameters were substantially reduced, frost resistance was better, resistance against de-icing salts was found to be slightly worse but still meets very well the required criteria. It is reported that the chemical resistance of concrete with 10% of Metakaolin instead of Portland cement in distilled water and HCl is better than for Portland cement concrete.

Hisham M. Khater (2010)made an experimental study and determined the resistance of mortar specimens incorporating 0%, 5%, 10%, 15%, 20%, 25% and 30% metakaolin to the magnesium chloride solution. Results confirmed that specimens with high replacement level of metakaolin showed higher resistance to magnesium solution. Due to the reduction ocalcium hydroxide and the increase of secondary C–S–H in the cement matrix, Metakaolin provide a good resistive agent to aggressive chloride solution by consuming liberated lime and so prevent the formation of Friedel's salt. The maximum development of compressive strength was achieved for the specimens made from Ordinary Portland cement-Metakaolin blended cement mortars containing a metakaolin content of 25% by weight. Bulk densities of all Metakaolin mortar specimens were between 1.4-2 gm /cm3.

Pacheco Torgal.F et al (2011) determined the effect of Metakaolin and Fly ash on strength and durability of concrete. The durability was found by three methods namely water absorption, oxygen permeability and concrete resistivity. They reported that partial replacement of Portland cement by 30% fly ash leads to serious decrease in early age compressive strength than the reference mix made with 100% Portland cement. The use of hybrid of them at 15% Fly ash and 15% Metakaolin based mixtures resulted in minor strength loss at early stages but showed outstanding improvement in durability.

Hemant Chauhan et al (2011) made an attempt to use industrial wastes like activated Fly ash, Iron Oxide and Metakaolin as supplementary cementitious materials in various proportions. Using these mineral admixtures with OPC cement, five different types of concrete mixtures were prepared and same were used to find compressive strength of concrete cubes at 3,7,14,28 and 56 days. When OPC was replaced up to 42% with metakaolin, it gives strength up to 40.67 N/mm2at a water cement ratio of 0.40 and at 0.55 ratio, it gave strength up to 25.47 N/mm2at 56th day. They reported that it was possible to make the concrete economical by 42% replacement of cement with different percentages of mineral admixtures like Fly ash (30%), Metakaolin (10%) and iron oxide (2%).

Muthupriya.P et al (2011)performed an experimental investigation on the behavior of High Performance Reinforced Concrete column (HPRC) to assess the suitability of HPRCcolumns for the structural applications. High performance concrete was prepared by partial replacement of Ordinary Portland cement with Metakaolin and Fly ash. The test results showed improvements in strength, brittleness and durability. The optimum replacement level for Metakaolin and Fly ash was reported as 7.5%.they reported that the compressive strength of high performance concrete containing 7.5% of Metakaolin was 12% higher than the normal concrete.

Kannan.V and Ganesan K(2012) investigated the effects of Rice husk ash, Metakaolin and their combinations when used as replacement for blending component in cement. The properties of blended cement mortar were investigated which included physical properties, chemical properties, setting time, compressive strength and saturated water absorption. The enhancement of compressive strength in percentage were 20.9% at 15% replacement of Rice husk ash, 17.42% at 25% replacement of metakaolin and 24.61 % at 30% replacement of Rice husk ash for a Metakaolin combination of (1:1 ratio).Water-Binder ratio at all replacement levels and the decrement in percentage of saturated water absorption were 25% at 25% replacement of Rice husk ash, 37.5% at 25% replacement of Metakaolin and 39.58% at 40% replacement of Rice husk ash for a Metakaolin combination of (1:1 ratio).

Murali.G and Sruthee P(2012) experimentally studied the use of Metakaolin as a partial replacement substance for cement in concrete. The use of Metakaolin in conrete effectively enhanced the strength properties. The optimum level of replacement was reported as 7.5%. The result showed that 7.5% of Metakaolin increased the compressive strength of concrete by 14.2%, the split tensile strength by 7.9% and flexural strength by 9.3%.

Paiva.H et al (2012)determined the effect of Metakaolin on strength and workability of concrete. The experimental results showed that the use of Metakaolin decreased the workability and to get the required slump, High range water reducing admixtures (HRWRA) were essential. HRWRA resulted in deflocculation of Metakaolin particles and thus a well dispersion of Metakaolin particles were achieved. The work concluded that use of HRWRA was very essential in concrete containing fine particles like Metakaolin to achieve well dispersion and better results.

Erhan Guneyisi et al (2012) made an investigation to determine the effectiveness of metakaolin (MK) and silica fume (SF) on the mechanical properties, shrinkage, and permeability related durability of high performance concrete. Mechanical properties were evaluated by means of compressive and splitting tensile strength. Water absorption and gas permeability tests were carried out to find out the permeation characteristics of the concrete with Metakaolin and Silica fume. The experimental results showed a considerable increase in the compressive strength properties of blended concrete than the control mix for different water cement ratios.

Vikas Srivastava et al (2012) investigated the suitability of silica fume and metakaolin combination in production of concrete. The optimum combined doses of silica fume and Metakaolin were found out as 6% and 15% (by weight) respectively. The specimens where cast and tested on 7th, 14thand 28 days. The 28th day compressive strength of concrete generally increased with the Metakaolin content for at all the Silica fume contents. The 7th day compressive strength of concrete was found to decrease with the increase in Metakaolin content for all the Silica fume contents.

Dojkov.I et al (2013) experimentally studied the reaction between Metakaolin-Ca(OH)2-water and Fly ash- Ca(OH)2-water. It was clear that during the initial period of curing (up to 7 days), Metakaolin combined lime with a very high rate. This indicated that the overall rate of the reaction taking place in early age of Portland cement - Metakaolin concretes and cement mortars was limited by the hydration of the cement phases. The reaction between Fly ash- Ca(OH)2-water was taking place at a moderate rate in the initial age as compared with Metakaolin-Ca(OH)2-water. The experimental results justified the possible combined use of Metakaolin-Fly ash-Portland cement in concrete industry.

3. CONCLUSIONS

From this literature survey, it was found that cement can be replaced effectively with Supplementary Cementitious Materials(SCM's) like Metakaolin. In the case of strength and durability, the SCM's shows better results than normal mixes. With regard to workability and setting time, Metakaolin generally required more superplasticizer and it reduces the setting time of pastes as compared to control mixtures. When compared with cement, the use of Metakaolin may be uneconomical due to its high cost whereas it is economical in the aspects of durability and strength.

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