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Influence of Metakaolin in Concrete Mixture: A Review

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ABSTRACT :*The present age is an age of overall development of civilization in its living environments and comforts. So there is always a need of superior and durable building materials. The recent developments in concrete technology has shown the use of alternate additives having cementitious properties in cement as .fly ash, silica fume, metakaolin, blast furnace slag etc. Every addition of above materials has indicated some improvements in the cementing and mechanical properties of cement. Presently the use of metakaolin is gaining lot of importance in partial replacement of cement. It is because metakaolin has increased various strengths of concrete and improved durability.*
KEYWORDS *- Pozzolanic materials, Ordinary Portland cement, Metakaolin, Mechanical properties, and durability*.

I. INTRODUCTION

Metakaolin (MK) is very much different from other supplementary cementitious materials like fly ash, slag or silica fume as it is a not a by-product of an industrial process.MK is a pozzolanic material . It is a thermally activated aluminosilicate material with high pozzolanic activity comparable to or exceeded the activity of fume silica [1]. And it is generated by calcination of kaolin clay at temperature of between 650°C and 800°C depending on the purity and crystallinity of the precursor clays [2]. Kaolin, also known as china clay, is a natural clay formed by chemical weathering of aluminium silicate minerals like feldspars through a complex sequence of events. It is relatively pure clay predominantly consisting of kaolinite ($Al_2Si_2O_5(OH)_4$), associated with other clay minerals like dickite, halloysite, nacrite and anauxite. Kaolin is commercially valued for its whiteness and fine particle size. Ambroise et al. [3] demonstrated that MK can also be obtained by the calcination of indigenous lateritic soils at 750– 800 °C. Another source for the production of MK is that of calcining waste sludge from the paper recycling industry [4].

Table1. Shows the chemical composition of ordinary portland cement (53 grade) and metakaolin

Table 1. Chemical composition of ordinary portland cement (53 grade) and metakaolin

Chemical composition	Abbreviation	Cement (%)	Metakaolin (%)
Silica	SiO2	34	54.3
Alumina	Al2O3	5.5	38.3
Ferric Oxide	Fe2O3	4.4	4.28
Calcium oxide	CaO	63	0.39
Magnesium oxide	MgO	1.26	0.08
Sodium oxide	Na2O	0.1	0.12
Potassium oxide	K2O	0.48	0.50
Sulphuric anhydride	SO3	1.92	0.22

When cement is partially replaced with Metakaolin, it reacts with byproduct calcium hydroxide and results in extra C-S-H gel. For strength development in cement and cement based concrete C-S-H gel is the sole cause. The chemical reaction is given below.

Cement + Water = C-S-H gel + Calcium hydroxide
Calcium hydroxide + Metakaolin = C-S-H gel

II. LITERATURE SURVEY

The Several researchers have studied on various parameters by replacing the cement by metakaolin, which includes fineness, mineral composition, workability, various strengths of cement mortars and concrete, permeability, chloride permeability, resistance to chemical attack, sorphtivity, durability, alkali aggregate reactivity etc.

S.Wild et al. [5] studied the mechanism of increasing the strength due to addition of metakaolin contents (0–30%) for different curing periods of 1 to 90 days . The observed results establish that there is an optimum OPC replacement level of 20 wt% MK and that the contribution which MK makes to strength is restricted beyond 14 days.

Sabir.B.B et al. [6] studied 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 addition of metakaolin as a pozzolana will help in the development of early strength and some improvement in long term strength.

Jian-Tong Ding et al. [7] conducted several experiments 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.

Xianyu Jin et al. [8] reported the improvements in mechanical properties of concrete by addition of mineral admixtures such as silica fume, slag, fly ash, and metakaolin, on the mechanical behavior of young concrete under either uniaxial compression or tension. The uniaxial compression and uniaxial tension tests have been conducted on the concrete specimens at ages of 1/2, 1, 2, 3, 7, and 28 days. By utilizing the circumferential control and adaptive deformation control, the complete stress-strain (deformation) curves have been obtained for young concrete under either uniaxial compression or uniaxial tension. The experimental results show that the different mineral admixtures do have different influences on properties of young concrete. Metakaolin shows the best enhancement on the mechanical properties of young concrete generally.

The empirical formula for evaluating compressive strength of young concrete is proposed in this paper. It takes the following form:

$fcm(t) = 0.23(\ln t + 1) fc28$

fcm(t)=compressive strength at age t days and

fc28 =compressive strength of at 28-days age

Badogiannis et al. [9] studied the properties of concrete by replacing either cement or sand in percentages of 10% or 20% by weight of the control cement content by metakaolin from poor Greek kaolin and commercial metakaolin.. Eight different mixes were used to produce high-performance concrete, replacing either cement or sand in percentages of 10% or 20% by weight of the control cement content by metakaolin. The efficiency factor (k-value) was used to evaluate the strength development of metakaolin concrete. The produced metakaolin as well as the commercial one imparts a similar behavior with respect to the concrete strength. Both metakaolins exhibit very high k-values up to 3.0 at 28 days, giving an excellent performance

J.M. Justice et al [10] Studied the behavior of two metakaolins differ by their surface area (11.1 vs. 25.4 m^2/g) as supplementary cementitious materials (SCMs) in concrete mixes . Mechanical properties like compressive, splitting tensile, and flexural strengths and elastic modulus were studied for 8% weight of cement replacement by MK and silica fume compared to control mixtures at water-to-cement ratios of 0.40, 0.50, and 0.60 where no SCM .Splitting tensile, flexural strengths and elastic modulus increased and Setting time decreased in the pastes with both metakaolins as compared to control mixtures. Due to alkali-silica reaction both metakaolins reduced rapid chloride ion permeability and expansion when compared to silica fume and control mixtures. Both metaklaolins performed superior to silica fume but finer metakaolin gave better results.

Nabil M. Al-Akhras [11] studied the the durability of concrete to sulfate attack, replacing cement , 5%, 10%, and 15% by weight of cement with metaaolin (MK) . The parameters like water to binder ratio (0.5 and 0.6), initial moist curing period (3, 7, and 28 days), curing type (moist and autoclaving), and air content (1.5% and 5%) also investigated.Concrete specimens were immersed in 5% sodium sulfate solution after the specified initial moist curing period for a total period of 18 month. By measuring expansion of concrete prisms, compressive strength reduction of concrete cubes, and visual inspection of concrete specimens to cracks the degree of sulfate attack was assessed. Increase in metakaolin replacement level increases the sulfate resistance of metakaolin concrete. The resistance to sulfate of MK concrete at lower w/b ratio of 0.5, autoclaved MK concrete and the air entrained MK concrete was found superior.

Erhan Gu neyisi et al [12] studied the behavior of plain concrete and metakaolin replacement with 0 to 20% of ortland cement by weight in concrete with two water binder (w/b) ratios of 0.35 and 0.55 under air and water curing . At all cement replacement levels under both air and water curing the properties like compressive strength, sorptivity, and chloride penetration with age are compared with those of the control concrete. sorptivity and chloride permeability of concrete depending mainly on replacement level of MK, w/b ratio, curing condition, and chloride exposure period , reduced due to the addition of MK . Also found that Metakaolin concretes looses compressive strength and permeability-related durability than the plain concretes due to inadequate or poor curing.

J. M. Justice et al. [13] evaluated the performance of two metakaolins varied by their surface area (11.1 vs. 25.4 m^2/g) as supplementary cementitious materials for the effect of metakaolin fineness on effective pozzolanic reraction, Calcium hydroxide consumption, and pore structure enhancement through measurements of workability, setting time, strength, elastic modulus, heat evolution, calcium hydroxide content, and surface area. when the finer metakaolin was used compressive and flexural strength of concrete were greater and improved at a faster rate.The increased early age flexural strength by as much as 60% of concrete due to addition of metakaolin. At the lower water-to-cementitious materials ratio the effect of metakaolin surface area on compressive strength was more clear. At the lowest w/cm, 0.40 , compressive strength iprovement found in the metakaolin–cement concretes than the ordinary concretes.The greater and more rapid heat evolution observed in greater surface area metakaolin concrete indicating a higher reactivity and a greater rate of calcium hydroxide formation. After 14 days Both metakaolins decreased calcium hydroxide content compared to controls and after 28 days more refined pore structure compare to controls was observed through surface area measurements.

Abid Nadeem et al. [14] analyzed the chloride permeability performance of seven concrete and three mortar mixes with varying proportions of metakaolin (5, 10 and 20%)and fly ash (20, 40 and 60%) as partial replacement of ordinary Portland cement (PC)exposed to 200, 400, 600 and 800°C.Chloride permeability values were extremely low for unheated specimens. chloride permeability was higher but in adequate limits at 200°C, than that at room temperature 27°C. Once the exposure of 400°C, most of the concrete specimens in moderately permeable condition and after the exposure of 600 and 800°C concrete is highly chloride permeable. For temperatures up to 200°C, all metakaolin concrete specimens and at all temperatures FA concrete specimens had lower chloride permeability than PC concrete. At 600°C or above concrete is more chloride permeable than mortor which is an indication of degradation.

Jiping Bai et al. [15] studied optimization and prediction of consistency of admixture concrete (PC,+FA +MK) for better construction. statistical models were prepared for predicting the consistency of concrete with FA and MK at graduated replacement levels of up to 40% and 15%, respectively. The model could successfully predict the consistency parameters like slump, compacting factor and Vebe time with good accuracy.The experimental findings within ±5%.

Chao Li et al. [16] Studied two main models of alkali-activated cements, one is the activation of slag (Si+Ca) and the other is activation of metakaolin (Si+Al). This study reviews current knowledge about the comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements, including the general properties of slag and metakaolin, hydration products reaction mechanisms and the role of Ca and Al. Models could predict results with good degree of accuracy.

Eva Vejmelkova et al. [17] studied high performance concrete (HPC) with replacement of Portland cement by 10% of metakaolin for physical mechanical and fracture properties, durability , hydric and thermal properties and chloride binding characteristics are measured and proved to improve all these after 28 days. Its Chemical resistance to distilled water and HCl is found to be better.

Hisham M. Khater [18] carried out research analysis on mortar specimens adding 0-30% metakaolin produced by firing Kaolin at 820 °C for 2 hrs for the resistance to the magnesium chloride. Mortar specimens with a high replacement level of metakaolin showed higher resistance to magnesium chloride solution due to, the reduction of calcium hydroxide and the increase of secondary C–S–H in the cement matrix. Compressive strength got increased replacing up to 25% wt of cement by metakaolin in OPC due to good improvement in matrix structure of dense quality.

Pacheco Torgal.F et al. [19] studied the effect of metakaolin and fly ash on strength and concrete durability. The durability of concrete was studied by different parameters like water absorption, oxygen permeability and concrete resistivity. Compressive strength decreases when replacement of cement by 30% fly ash, whereas replacement of cement by 15% fly ash and 15% metakaolin is responsible for minor strength reduction but improvement in durability.

Antoni M et al. [20] investigated that 45% of cement replacement by 15% of limestone and 30% of metakaolin in mortars presents better mechanical properties at 7 and 28 days than the 100% PC mortar . Using X-ray diffraction, thermogravimetry analysis and isothermal calorimetry studied matrix development in pastes. Reaction between calcium carbonate and alumina from the metakaolin results in forming supplementary "alumina, ferric oxide, monosulfate " phases and stabilizing hydrous calcium aluminium sulfate (ettringite). Using simple mass balance calculations derived from thermogravimetry results, presented thethermodynamic simulation for the system, which concurs with the experimental observations. Gypsum influences the early age strength, addition should be carefully balanced with calcined clays.

A.A. Ramezanianpour et al. [21] studied the performance of concrete mixtures with local metakaolin in terms of compressive strength, water penetration, sorptivity, salt ponding, rapid chloride permeability test and electrical resistivity which carried out at 7, 28, 90 and 180 days. XRD and SEM tests carried out for the micro structural development of the cement pastes with metakaolin. Concrete mixtures prepared by replacing 0%, 10%, 12.5% and 15% by mass of cement with metakaolin at water/binder (w/b) ratios 0.35, 0.4 and 0.5 having a constant total binder content of 400 kg/m^3. Results showed that concrete with metakaolin had superior compressive strength and metakaolin enhanced the durability of concretes and reduced the chloride dispersion. Demonstrated an exponential relationship between chloride permeability and compressive strength of concrete and a linear relationship between rapid chloride permeability test and salt ponding test results.

Abid Nadeem et al. [22] evaluated the performance of Fly Ash (FA) and Metakaolin (MK) mortar at elevated temperatures. Analysis carried out for the partial replacement of cement with MK from 5% to 20%, FA from 20% to 60% and temperatures from 27^o C to 800^o C. Qualitative analysis of the microstructure of heated and unheated mortar was performed by Scanning Electron Microscope (SEM) while quantitative analysis was performed on SEM images using Image Pro-plus software. For all mixes, compressive strength decreased while charge passed increased with the increase in temperature from 27^0 C to 800^0 C and major strength and durability loss occurred after 400^0C, which was considered as critical temperature for degradation.

R. San Nicolas et al. [23] studied the performance and durability of concrete where flash- calcined metakaolin (MKF) was used as Portland cement replacement. The replacement rate was set at 25% of MKF in six different types of concrete, from immediate release concrete to self compacting concrete and from low to high performance concrete, including concrete for general or structural purpose. MKF concrete reduces the, permeability, chloride ion penetration and increases strength.

Efstratios G. Badogiannis et al. [24] studied evaluate the durability of Self-Compacting Concrete (SCC) with inclusion of metakaolin (MK). Cement or limestone powder was replaced by MK at different levels. Open porosity, sorptivity, water and gas permeability, chloride penetrability were evaluated against a reference mixture. The inclusion of MK improved durability, but no enhancement on the near surface water permeability of the concrete. Equations expressing the effect of the replacement level on the examined properties were formulated, whenever appropriate. The major effect of MK as a replacement material was observed in the chloride penetration resistance.

III. CONCLUSION

The study of various researches on use of metakaolin in cement mortar and concrete can be summarized as follows.

1. Use of 25% MK in replacement of cement increases strengths of all basic properties viz. compressive strengths, flexure strengths, split strengths, tensile strengths etc. and durability improvement.
2. Water permeability, absorption was much improved in use of metakaolin which leads to increase in density of concrete.
3. Use of metakaolin in preparing acid resistance concrete such as chloride permeability, sulfate resistance showed good results.
4. Use of metakaolin showed better improvement in flow ability of concrete and cement mortar.
5. It reduces efflorescence which occurs when calcium is transported by water to the surface where it combines with carbon dioxide from the atmosphere to make calcium carbonate, which precipitates on the surface as a white residue.
6. It enhances workability and finishing of concrete
7. It reduces shrinkage due to particle packing.
8. It can be used to form of high performance, high strength, and lightweight concrete, precast and poured-mold concrete, fiber cement and ferrocement products, glass fiber reinforced concrete, etc.

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