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EFFECT OF METAKAOLIN ON VARIOUS PROPERTIES OF CONCRETE- AN OVERVIEW

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ABSTRACT

There is an increasing trend of utilization of waste/non-conventional materials in cement and concrete matrices. These materials are often used as a partial replacement substance for cement, reducing the cost of construction and help to overcome the deficiencies associated with the use of Ordinary Portland Cement (OPC). These materials generally improve the strength of cement/concrete matrices and other quality aspects. Metakaolin is a waste/non-conventional material which can be utilized beneficially in the construction industry. It is a proven fact that use of metakaolin in concrete increases the compressive, tensile, flexural and bend strength and modulus of elasticity. This paper presents the review of investigations carried out to find the suitability of metakaolin in production of concrete. This paper presents an exhaustive literature review on the effect of metakaolin on strength and durability aspects of concrete.

Keywords: Chloride Attack, Compressive Strength, Metakaolin, Permeability, Resistivity, Temperature, Water Absorption.

I. INTRODUCTION

Concrete is one of the most extensively used construction materials. Cement is a major constituent material of concrete. Production of cement consumes natural materials leading to environmental concerns in terms of utilization of raw materials and emissions of CO_2 [1,2]. In this view waste materials disposed from industries and or pozzolana materials containing reactive silica or alumina are used in cement. They react with $Ca(OH)_2$ a byproduct of cement hydration, in the presence of water and forms calcium silicate Hydrate gel. Replacing cement by pozzolana leads to lower heat of hydration. Commonly used industrial waste materials are fly ash, bottom ash and blast furnace slag. Alternative pozzolanic materials such as metakaolin, silica fume, wood ash, lime stone, calcined clays are also found to be used in concrete.[3,4,5].

Use of cement replacing materials (CRMs) is a fundamental idea in developing low cost construction materials. Concrete is the most widely used and versatile building material which is generally used to resist compressive forces. By the addition of some pozzolanic materials, the various properties of concrete namely workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica of the pozzolanic material and calcium hydroxide, produced during the cement hydration reactions [11] Portland cement consists of about 80% calcium silicate:

Alite (C_3S) and belite (C_2S)

These will react with water. The following equations summarize the chemical reaction [39];

$C_3S + 3H = CSH + 2\ CH$

$C_2S + 2H = CSH + CH$

The final structure consists of about 75% calcium silicate hydrate (CSH) and 25% hydrated lime (CH)

The hydrated lime (CH) also called calcium hydroxide or portlandite will react with pozzolana, forming more CSH phase

CH + S -> CSH

CH + S + A -> C_2ASH_8

Kaolinite clay, widely available in the earth crust are treated with heat of 6000^{o}C to 8000^{o}C leads to de hydroxylation of the crystalline structure of kaolinite to form metakaolin [6,7,8,9,5]. Use of metakaolin as partial replacement substance for cementin concrete started in 1960's and there is a resent increase in it [2]. Experimental studies on use of metakaolin in concrete shows that, presence of metakaolin in concrete improves its mechanical properties and durability properties [10,8,11,12].

Table 1. Physical and chemical properties of metakaolin from Vikas Srivastava et al[22]

Property	Metakaolin
Specific gravity	2.5
Mean grain size (µm)	2.54
Specific area (cm^2/g)	150000-180000
Colour	Ivory to cream
Chemical compositions (%)	
Silicon dioxide (SiO_2)	60-65
Aluminium oxide ($A1_2O_3$)	30-34
Iron oxide (Fe_2O_3)	1.00
Calcium oxide (CaO)	0.2-0.8
Magnesium oxide (MgO)	0.2-0.8
Sodium oxide (Na_2O)	0.5-1.2
Loss on ignition	<1.4

II. METAKAOLIN: PRODUCTION AND SOURCES

The main sources of metakaolin are kaolin clay and paper sludge after suitable treatment. Metakaolin can also be obtained by the calcination of indigenous lateritic soils. . The development of pozzolanic properties in fired clays mainly depends on the nature and abundance of clay minerals in the raw material, the calcination conditions and the fineness of the final product. The calcination temperature producing the reactive state is usually in the range of 600–800^{o}C. On heating, re crystallization and formation of MK ($2SiO_2Al_2O_3$) or mullite ($3Al_2O_3\_2SiO_2$) take placeresulting in a decline of material reactivity. The following section details the process of production of metakaolin.

III. PRODUCTION OF METAKAOLIN FROM KAOLINE

Kaolin is a phyllosilicate, consisting of alternate layers of silica and alumina in tetrahedral and octahedral coordination, respectively. This electrically neutral crystalline layer structure, which is a common characteristic of clay minerals, leads to a fine particle size and plate like morphology and allows the particles to move readily over one another, giving rise to physical properties such as softness, soapyfeel and easy cleavage. Kaolinite is the mineralogical term for hydrated aluminium disilicate, $Al_2SiO_5(OH)_4$.[36]. Under normal environmental conditions, kaolin is quite stable. However, when kaolin heated to temperature of 650–900 ^{O}C it loses 14% of its mass in bound hydroxylions.

This heat treatment, or calcination, breaks down the structure of kaolin such that the alumina and silica layers become puckered and lose their long-range order. Result of this de hydroxylation and disorder is metakaolin, a highly reactive transition phase, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications.

IV. EFFECT OF METAKAOLIN ON VARIOUS PROPERTIES OF CONCRETE

4.1 Effect of Metakaolin on Strength of Concrete

Bilir [14] studied the effect of the non-ground metakaolin, as fine aggregate in mortars, on restraint shrinkage cracking, flexural and compressive strengths. The replacement levels of fine aggregate with metakaolin were ranging from 10% to 100% with an increment of 10%. It has concluded that the optimum ratios for use of non ground metakaolin, in mortars, were about 40 and 50% for flexural strength and compressive strength, respectively. Regarding the restraint shrinkage cracking, the crack widths were in acceptable range for all non-ground metakaolin replacement levels up to 100%.

Yuksel and Bilir [15] studied the possible usage of metakaolin as sand replacement in production of plain concrete elements. Compressive strength, flexural strength, freeze-thaw and surface abrasion resistance were studied. Sand was partially replaced with BA at replacement levels of 20%, 30%, 40% and 50%, by volume, whilst it was partially replaced with metakaolin at replacement levels of 20%, 30% and 40%. The results showed that the usage of partially fine aggregate of these materials had more beneficial effects on durability characteristics of plain concrete elements.

Ismeil [17] studied the compressive strength, of concretes, in which natural sand was partially replaced with metakaolin at levels of 5%, 10% and 15%, by weight, at different w/c ratios of 0.5, 0.55 and 0.6. The results showed that there is improvement of 17% in the compressive strength with the inclusion of metakaolin.

4.2 Water Absorption

V. Kannan and K. Ganesan[23] experimentally studied the effect of metakaolin on saturated water absorption of concrete. Cylindrical blended cement mortar specimens of 100 mm diameters and 50 mm thick were cast from each mix and the saturated water absorption values were determined after 28 days of curing as per ASTM C

642.Figure 2 and 3 shows the variations of the saturated water absorption in percentage for all blended cement mortars mix. It is observed that the saturated water absorption for all rice husk ash, metakaolin and their combination mixes are less than that of ordinary cement mortar. The maximum replacement level of cement is up to 25% for Rice Husk Ash, 25% for metakaolin and 40% for their combination. It is probably due to the presence of pozzolanic materials that leads to greater precipitation of cement gel products than that occurs in ordinary Portland cement alone, which more effectively block the pores helping to reducing saturated water absorption.Compressive strength of the cement mortar blended with rice husk ash, metakaolin and their combinations showed a considerable improvement.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, metakaolin combination (1:1 ratio).

Andrade et al. [13] incorporated metakaolin as a substitute material for natural sand in the production of concrete. The replacement levels of sand with metakaolin were 25%, 50%, 75% and 100%.Capillary absorption and compressive strength were investigated. The results indicated that the capillary absorption potential with water was higher in mixtures that containing metakaolin.

4.3 Concrete Resistivity

Many factors influence the electrical resistivity of concrete, including water/cement ratio, cement type, pozzolanic admixtures, degree of hydration, porosity, the moisture content, the composition of the pore solution, pore size, transport property and connectivity [28]. Electrical resistivity of concrete, is one of the most important parameters that can help to assess corrosion of steel in concrete. It is today widely accepted that the corrosion rate decreases with increasing concrete resistivity under common environmental exposure conditions (excluding submerged structures).

Hesam Madani et al. [37] Evaluating concrete properties is possible withelectrical resistivity, and electrical resistivity can be used forcondition surveying of concrete structures. It is revealed thata strong relationship exists between chloride diffusivity and electricalresistivity. To investigate the transport property of theconcrete experiencing repeated freeze and thow cycles, the electrical propertiesof the concrete samples were examined. A four-point probeResitest-400 type resistivity meter was used to measure the electrical resistivity of the concrete specimens.

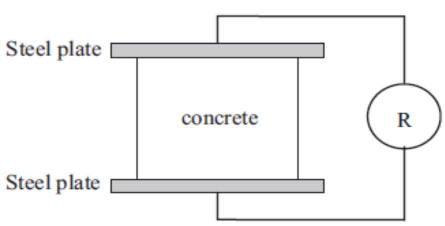

Fig. 1 Resistivity testing by two-electrode method [38]

S.A.Bhalchandra et al. [46] found that the electrical resistivity increases with the age of specimen and found maximum at 28days of curing period with a metakaolin content of 10% replacement with cement. At 10% MK content with cement replacement the 7day compressive strength for w/b ratio’s of 0.45, 0.5, 0.55 and 0.58 are increased by 36.52%, 21.13%, 27.24%, 32.74% respectively.

Rama Mohan Rao, Vinodkumar [50] experimentally studied electrical resistivity of ternary blend concrete. Class C fly ash and metakaolin were used to replace cement at various percentages. Author proposed a hyperbolic equation for electrical resistivity estimation.

4.4 Concrete Permeability

The effects of metakaolin on the transport properties of concrete have been of more interest in recent years. Khatib and Clay [40] measured the water absorption of concrete by capillary suction after 90 days of curing and reported that for 15% metakaolin, the coefficient of water absorption reduced by 30%. And it alsoshowed a reduction by 20% for water absorption was also reported for 15% metakaolin (9.7% mass). Zhang and Malhotra [41] showed that 10% metakaolin can improve the resistance to chloride ion penetration by 88%. Boddy et al. [42] reported that the bulk coefficients of diffusion for concrete can reduce up to 70% in 12% metakaolin concrete. Badogiannis and Tsivilis [43] also reported a decrease of chloride permeability of 90% (240 coulombs) in concrete with 20% metakaolin.

M. Shekarchi et al. [44] measured the transport properties in terms of water penetration, gas permeability, water absorption, electrical resistivity, and ionic diffusion, were improved up to 50%, 37%, 28%, 450%, and 47%, respectively while alkali–silica reaction expansion was reduced as much as 82% in 15% metakaolin mix. The performance of 10% silica fume addition in improving the transport properties was observed to fit between the 10% metakaolin and 15% metakaolin mixes.

Hisham M. Khater [51] experimentally studied the resistance of mortar specimens incorporating 0%, 5%, 10%, 15%, 20%, 25% and 30% metakaolin (produced by firing Kaolin at 820 °C for 2 hrs) to the magnesium chloride solution. Results confirmed that mortar specimens with a high replacement level of metakaolin showed higher resistance to magnesium solution. The maximum development of compressive strength was achieved for the specimens made from OPC-MK blended cement mortars containing a metakaolin content of 25 wt.%. Author concluded that metakaolin provide a good resistance to aggressive chloride solution by consuming liberated lime and so prevent the formation of Friedel's salt.

4.5 Effect of Temperature

Concrete's thermal properties are more complex than for most materials because not only is the concrete a composite material whose constituents have different properties, but its properties also depending on moisture and porosity [47]. Exposure of concrete to elevated temperature affects its mechanical and physical properties. Elements could distort and displace and under certain conditions, the concrete surfaces could spall due to the build up of steam pressure. Because thermally induced dimensional changes, loss of structural integrity, and release of moisture and gases resulting from the migration of free water could adversely affect plant operations and safety, a complete understanding of the behaviour of concrete under long-term elevated-temperature exposure as well as both during and after a thermal excursion resulting from a postulated design-basis accident condition is essential for reliable design evaluations and assessments. Because the properties of concrete change with respect to time and the environment to which it is exposed, an assessment of the effects of concrete aging is also important in performing safety evaluations [48].

4.5.1 Effect of Elevated Temperature on Compressive Strength of Metakaolin Concrete

Viswanadha Varma D et al. [49] recently experimentally investigated the effects of high temperature on compressive strength and elastic modulus of high strength concrete containing metakaolin. This paper presents the feasibility of the usage of metakaolin usage as partially replaced material for cement in M50 grade concrete. Initially four trails were conducted by partially replacing cement with metakaolin starting from 0% to 20% with the gradual increase of 5% for each trail and observed that the maximum strength was occurred at 15% replacement of metakaolin and after that at 20 % the strength began to decrease. Concrete cubes were cast with 0% and 15% replacement of cement with metakaolin. The compressive strength for M50 grade was assessed on $28^{th}$and 91^{st} day. Those cubes which were cured for 28 days and 91 days were kept in furnace at various temperatures for duration of 1hour, 2 hours and 3 hours. It was found that after an increase in compressive strength at 100ºC, the metakaolin suffered a more severe loss of compressive strength than 0% MK at higher temperatures. Explosive spalling was observed in high temperature and frequency increased with higher metakaolin contents. After 300ºC the severe strength loss was due to very dense pore structure of metakaolin which enhanced the buildup of vapour pressure upon heating and resulted in spalling and cracking.

Gyu-Yong Kim et al. [35] experimentally investigated the effect of high temperature on compressive strength and elastic modulus of high strength concrete containing metakaolin. The aim of the study was to assess the effect of elevated temperatures ranging from 200 to 700^{O} C on the material mechanical properties of high-strength concrete of 40, 60 and 80 MPa grade. During the strength test, the specimens are subjected to a 25% of ultimate compressive strength at room temperature and sustained during heating, and when the target temperature was reached, the specimens are loaded to failure. The tests were conducted at various temperatures (200 to 700^{O}C) for concretes made with various water binder ratios. The results show that the relative values of compressive strength and elastic modulus decreases with increasing compressive strength grade of specimen.

V. CONCLUSION

Metakaolin is highly pozzolanic and reactive material. Addition of metakaolin in concrete considerably improves its strength and durability properties. Metakaolin has a very positive effect on the concrete strength after 2 days and specifically at 28 days and 90 days. Metakaolin concrete exhibits significantly lower chloride permeability, gas permeability, sorptivity and pore size compared with OPC concrete. The optimum temperature for heating kaolin in order to obtain metakaolin with a high pozzolanic index is still different from one researcher to another. The heating period also is still exactly undetermined. Ternary mixtures have promising future for implementation in future bridge decks and pavements to delay chloride induced corrosion process.

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