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A Review on Use of Metakaolin in Cement Mortar and Concrete

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ABSTRACT: Concrete a widely used construction material, consumes natural resources like lime, aggregates, water. In this content an interest was made by civil engineers to replace the composite concrete material with industrial wastes, agricultural wastes, and waste glass. In this content metakaolin was a pozzolanic material used in wide range in partial replacement of cement in concrete which was treated as economical and also due to its pozzolanic action increases strength and durability properties of concrete. In view a review was done in utilization of metakaolin in concrete as an partial replacement material to cement which has given excellent results.

KEYWORDS: Metakaolin, Portland cement, cement replacement, cement, concrete.

I. INTRODUCTION

Concrete the most extensively used construction material which consumes natural materials leading to environmental concerns in terms of utilization of raw materials and also emissions of Co_2 while production of cement [39,14]. In view waste materials disposed from industries and or/pozzolana materials containing reactive silica or alumina are used in mixing with Portland cement, reacts with lime produced by cement hydration in the presence of water and thus forms harden with cement. 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 cementations materials such as metakaolin, silica fume, steel fibres, quarry dust, wood ash, lime stone, calcined clays are of interest in concrete.[7,17,40] Kaolinitic clay, widely available in the earth crust are treated with heat of 600^0c to 800^0c leads to de hydroxylation of the crystalline structure of kaolinite to form metakaolin [1,3,11,16,40]. Use of metakaolin in partial replacement of cement started in 1960's and interest in concrete was increased in recent year's [14]. Experimental studies in use of metakaolin in concrete improved mechanical properties and durability properties [10, 11, 12, 18].

II. METAKAOLIN IN MORTAR

Cement replacement with MK 20% in content gave maximum enhancement in pore refinement of pastes and compressive strength reduces when MK addition goes beyond 30% as cement replacement [1]. MK provides good resistance to aggressive chloride solution by consuming liberated obtained with OPC –MK blended cement mortars with 25% by weight of MK[18]. A special care should be taken when use of MK in cement mortar under magnesium sulfate attack as compressive strength loss and expansion was observed with mortar specimen compared without MK in magnesium sulfate environment[24]. Replacement of cement with flash metakaolin in mortars, showed better performance than control mortar, particularly in terms of mechanical properties. Saving upto 40% of clinker reduces energy consumption and amount of Co_2 emissions to atmosphere [40]. Mortars are prepared by lime and metakaolin with siliceous river sand volumetric ratio's of 1:1, 1:2, 1:3 (binder/aggregate) and replacements of 30 and 50% weight of lime by metakaolin which showed the highest pozzolonic reaction [32]. Replacement to cement at 10% MK and 15% MK shows better viscosity and shear stress and improved the cement paste flow ability [37]. Enhancement in compressive strength of 20.9% was observed at 15% replacement of rice husk ash, 17.42% at 25% replacement of metakaolin and 24.61% at 30% replacement of equal ratio's (1:1) of RHA and MK combination. Saturated water absorption was 25% at 25% replacement of RHA, 37.5% at 25% replacement of metakaolin and 39.58% at 40% replacement of RHA and MK combination [38].

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III. METAKAOLIN IN CONCRETE

A compressive strength of 50Mpa was designed by various percentages of metakaolin replacements of 5%, 10%, 15% and 20% in combination with 0%, 0.5%, 1% and 1.5% of crimped steel fibers by volume of concrete. Results showed that replacement of cement with 10% metakaolin and 1% addition of fibres is the optimum value for the property of hardened concrete compressive strength 23% of increased compressive strength was observed when compared with plain concrete. Higher percentages of replacement of volume of fibers blended with metakaolin show high elastic properties when unloaded, specimens tried to regain the deflection upon removal of loading and already cracked specimens when reloaded found that they withstand the applied loading up to the considerable level of loading. 10% cement replacement by metakaolin and 1.5% of volume of fibers the first cracking strength increases by 61% when compared to plain concrete and 96% increase in ultimate flexural strength when compared to plain concrete [2]. Replacement of cement by 10% with metakaolin decreased the percentage loss of compressive strength of concrete when exposed to 5% H_2So_4 in combination with crimped steel fibers with higher content. Durability studies revealed that 10% replacement of cement with metakaolin along with crimped steel fibers are more durable when compared to normal concrete exposed with HCL and H_2So_4 solution [4].

Portland cement when partially replaced with 20% metakaolin increased compressive strength and split tensile strength of concrete with increase in curing period increases for later ages of curing i.e, 7days , 28days and 90 days. And from XRD studies formulation of C-S-H gel with more intensity and portandite with less intensity may be responsible for more strength in presence of metakaolin [5]. It was found that electrical restivity was increased with the age 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 [6]. Concrete which is made by Portland cement (PC), pulverized fuel ash (PFA) and metakaolin are mixed thoroughly until uniform color was obtained. The PC-PFA mixes consists of 60% PC and 40% PFA with various levels of MK (0, 1%, 2%, 3%, 4%, 5%) and was found that strength was increased in concrete and for very small amounts of MK of 1% of PC reduced hydration heat output of up to 72 hours [7]. MK when combined with glass fiber reinforced concrete in combined with glass fiber reinforced concrete in M20 concrete for immersion in 5% HCL, H_2So_4 and $MgSo_4$ for 30days, 60days and 90days curing, resisted acid attacks. Least acid attack at 10% replacement of cement by metakaolin was observed and loss of compressive strength was reduced by 10% replacement of metakaolin, maximum loss was occurred in case of H_2So_4 acid immersion and least was observed for HCL acid immersion when compared out of three acids [8]. A literature review shows that 7% to 15% of cement can be replaced by metakaolin and in general at least 10% metakaolin is of interest in concrete. 15% MK may cause decrease in workability and dosage of super plasticizer is required [9].

Replacement of cement by 0,4,6 and 8% are made by MK and suitable increase in compressive strength, resistance to rapid chloride permeability was found. Compressive strength of high grade concrete was increased by 10.13%, 14.24% and 22.90% due to addition of metakaolin content of 4%, 6% and 8% respectively and found that rapid chloride permeability decreases with increase in metakaolin content [10]. An optimum percentage of 10% replacement of nano-metakaolin was found and increase of compressive strength varies between 5 to 38% for M20, 2-37% for M30, 3-13% for M40, 3-18% for M40, 3-18% for M50 grades of concrete. Increase of split tensile strength varies between 5 to 36% for M20, 2-13% for M30, 2-34% for M40, 2-26% for M40, 2-26% for M50 was observed [11].

Replacement of cement with metakaolin increased the strength properties of concrete when compared with conventional concrete [12]. Concrete mixes are made by 0, 5, 10 and 15% metakaolin replacement with cement was made and are exposed to normal and steam curing at 55^0c and found that 10% metakaolin usage was optimum for normal curing and 15% MK replacement of cement produced concrete showed higher pore volume results in high waster absorption are applicable in binder without any secondary protection of concrete like epoxy coating in extreme climate conditions with low PH value fields [13]. Use of natural zeolite and metakaolin in binary blended system up to 20% replacements, have a significant effect on durability properties of concrete which leads to reduction of cement content makes green and environmental concrete [15].

Metakaolin dealumination from Kankara city was done using novel approach and has given the silica alumina ratio required. [16]. Kaolin clay available in Dwekhla region in Iraq was examined for preparing metakaolin and was

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found that optimum calcination temperature was 700^0c and the optimum time of calcination at time of calcination temperature was one hour [19].Replacement of OPC for 42% with fly ash(30%) and metakaolin (10%) and iron oxide (2%) cost of concrete is reduced and strength was improved at 56 days and workability of concrete also improved with lower W/C ratio [20]. Blended cement made with partial replacement of cement with fly ash and metakaolin found improvement in workability, durability, dry shrinkage and permeability [21].

Chloride permeability test was conducted for replacement of OPC with 5%, 10% and 20% of MK content. All concrete specimens showed lower chloride permeability when compared with OPC concrete when exposed up to 200^0c [22]. Cement was replaced by 0, 5, 10 and 15% with metakaolin and also with silica fume. Both materials when replaced with cement showed increase in strength properties and also of free shrinkage, restrained shrinkage cracking and chloride diffusivity at all ages of curing [23]. Slump was reduced in 40% at 15% replacement level of high reactive met kaolin. Increment in strength was reduced with replacement of HRM content increased from 10% to 15% . Packing between the concrete materials was increased in addition of fine MK, 12% increase in strength compared to normal concrete was found at 7.5% replacement level of MK. Ductility parameters such as displacement ductility, curvature ductility properties improved when compared to normal concrete [25].

Use of MK accelerated initial setting time and final setting time remains unchanged. 15%. Optimum usage of MK was found where compressive strength, water penetration, gas permeability, water absorption, electrical resistivity and ion diffusion are improved by 20%, 50%, 37%, 28%, 40% and 47% respectively and 28 days ASR expansion was reduced as much as 82% [26]. Optimum utilization of MK was found to be 10% which was made replacement to cement by weight, compressive strength, young's modulus are increased from 0% to 10% of metakaolin and then decreased and slump decreased with increase in percentage replacement of metakaolin [27].

Strength and durability studies are improved for high performance concrete by addition of optimum content of 5% by weight of cement which are treated with chlorides and sulfate chemicals for a period of 180 days [28]. The compressive strength of high grade concrete was increased from 10.13% to 22.90% for replacement of cement by MK of 4% to 8% by weight of cement. Durability tests done by using water permeability reduced depth of penetration by 71% [29]. Three types of steel fibres were used by 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4% by weight of cementations materials at w/c ratio 0.27, compressive strength and split tensile strength are increased by addition of MK and steel fibres [30]. A combination of 6% silica fume and 15% MK by weight of cement replacement are found to be optimum dose for increase of compressive strength and slump was reduced with increase of MK content [31].

Four different concentrations of $CaCl_2$ were taken for mixing and curing environment in high performance metakaolin concrete (20% MK by replacement with weight of cement), compressive strength and split tensile strength where increased in concentration with $CaCl_2$ [33]. 5% of finer MK replacement gave higher compressive strengths and durability to resist to sodium sulphate attack was improved [41].

Improved durability with regard to metakaolin content from 0% to 30% by weight of cement, chloride ion permeability value decreased with metakaolin content, chloride ion penetration increased with increase in w/b ratio's [34]. With metakaolin and condensed silica fume replaced with cement in high strength concretes of M60 and M80 grades with steel fibers, 10% condensed silica fume and 5% MK blended concrete gave high strength without fiber reinforcement with increase in steel fibers percentage the compressive strength increased. High tensile strength was observed at 10% condensed silica fume, 5% MK and 1.5% steel fiber content [35]. Concrete with 8% MK and 1.5% steel fiber are observed with increase of compressive strength by 8.9% and tensile strength by 26.94% and flexural strength by 58.28% when compared with control concrete mix [36].

IV.CONCLUSION

The interest of use of metakaolin in cement mortar and concrete is of high. Use of metakaolin in concrete is of 25% in replacement of cement gave good strength results and durability improvement. Water permeability, absorption was much improved in use of metakaolin which leads to increase in density of concrete. Use of metakaolin in preparing acid resistance concrete such as chloride permeability, sulphate resistance showed good results. Improvement in use of

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metakaolin with silica fume, fly ash and steel fibres showed better results than conventional concrete. Use of metakaolin showed better improvement in flow ability of concrete and cement mortar.

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