Strengthening of Cement Concrete using Fly ash and Metakoline: A Review

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***Abstract* - Metakaolin is a cementitious material used as admixture to produce high strength concrete. In Korea, the utilization of this material sremained mainly limited to fireproof walls but began recently to find applications as a replacement for silica fume in the manufacture of high performance concrete. In order to evaluate and compare the mechanical properties and durability of concrete using metakaolin, the following tests were conducted on concrete specimens using various replacements of silica fume and metakaolin; mechanical tests such as compressive, tensile and flexural strength tests, durability tests like rapid chloride permeability test, immersion test in acid solution, repeated freezing and thawing test and accelerated carbonation test. Strength tests revealed that the most appropriate strength was obtained for a substitution rate of metakaolin to binder ranging between 10% and 15%. It was observed that the resistance to chloride ion penetration reduced significantly as the proportion of silicafume and metakaolin binders increased. The filler effect resulting from the fine powder of both binders was seen to ameliorate substantially the resistance to chemical attacks in comparison with ordinary concrete. Durability tests also verified that concrete using metakaolin bore most of the mechanical and durability characteristics exhibited by concrete using silica fume. The tests implemented in this study confirmed that metakaolin constitutes a promising material as a substitute for the cost prohibitive silica fume**

***Index Terms* - Fly-ash, Slag, Metakaolin, Concrete, Compressive strength, Cement, Coarse Aggregate, Pozzolanic, Cementitious.**

I. INTRODUCTION

It has been well recognized that the use of pozzolanic materials such as silica fume (SF) and fly ash (FA) is necessary for producing high performance concrete. These materials, when used as mineral admixtures in high performance concrete, can improve either or both the strength and durability properties of the concrete. In recent years, there has been a growing interest in the use of MK as a mineral admixture for a similar purpose [1–5]. A comprehensive review of the studies on the use of metakaolin as a partial pozzolanic replacement for cement in mortar and concrete has recently been presented by Sabir et al. [6]. Metakaolin is a thermally activated alumino-silicate material obtained by calcining kaolin clay within the temperature range 650–800 _C [6]. It contains typically 50– 55% SiO2 and 40–45% Al2O3 and is highly reactive. An important difference between MK and natural pozzolans or other types of artificial pozzolans is that MK is a primary product, while SF and FA are secondary products or by-products. Thus, MK can be produced with a controlled process to achieve the desired properties. It has been reported that the concrete incorporating 10% MK had a higher compressive strength than the control Portland cement concrete at all ages up to 180 days [3,4]. When compared with SF concrete at the same level of replacement, MK concrete showed a faster strength development at early ages, but had similar strength after 28 days [4]. With respect to the durability aspects, it has been reported that the resistance ofMK concrete to chlorideion penetration was significantly higher than the control concrete but similar to the SF concrete [4]. Overall, as concluded by Sabir et al. [6] after a review of existing studies, MK is a very effective pozzolan. When used as a partial replacement in concrete, it results in enhanced early strength with no detrimental effect to the long-term strength, and greatly improves the resistance to the transportation of water and diffusion of harmful ions. A number of studies have been conducted on the hydration process and microstructure changes of cement pastes containing MK [7–12]. These studies show that at early ages the rate of pozzolanic reaction is higher in MK pastes than in SF pastes, but after prolonged curing it becomes slower in MK pastes. When used in cement pastes with a higher water-to-binder (w/b) ratio (e.g. w/b = 0.55), MK results in smaller pore sizes but higher total porosity [8]. However, when used in high performance cement pastes (low w/b ratio), it reduces both the pore sizes and total porosity [12]. The present study is to relate the mechanical and durability properties of high performance MK concreteto their microstructure properties. Two series of concrete mixtures are prepared at the water-to-binder ratios of 0.3 and 0.5. The compressive strength and chloride penetrability of MK blended concretes are determined and compared with those of SF concretes. The porosity and pore size distribution of high performance MK and SF concrete mixes prepared with a w/b of 0.3 are determined using mercury intrusion porosimetry (MIP). The effect of MK and SF on the porosity of the interfaces between the cement matrix and aggregates is evaluated by comparing the data of the present study with the dataon the porosity of cement pastes reported in a separated paper [12].

II. FLY ASH

Fly ash used in this study was low-calcium (ASTM Class F) dry fly ash from Collie Power Station, Western Australia. Three batches of fly ash were obtained during the period of this study from 2002 to 2005. The chemical composition of the three batches of the fly ash, given in Table 3.1, was determined by X-Ray Fluorescence (XRF) analysis. As can be seen from Table1 that, for all batches of fly ash, the silicon and aluminium constitute about 80% of the total mass and the ratio of silicon to aluminium oxide is about 2. The chemical composition of the three batches of the fly ash, given in Table1, was determined by X-Ray Fluorescence (XRF) analysis. As can be seen from Table 3.1 that, for all batches of fly ash, the silicon and aluminium constitute about 80% of the total mass and the ratio of silicon to aluminium oxide is about 2.

Table 1: Chemical Composition of Fly Ash (% by mass)

Oxides	Batch-1	Batch-2	Batch-3
SiO_2	53.36	47.80	48.0
Al_2O_3	26.49	23.40	29.0
Fe_2O_3	10.86	17.40	12.7
CaO	1.34	2.42	1.78
Na_2O	0.37	0.31	0.39
K_2O	0.80	0.55	0.55
TiO_2	1.47	1.328	1.67
MgO	0.77	1.19	0.89
P_2O_5	1.43	2.00	1.69
SO_3	1.70	0.29	0.5
Cr	0.00	0.01	0.016
MnO	0.00	0.12	0.06
Ba	0.00	0.00	0.28
Sr	0.00	0.00	0.25
V	0.00	0.00	0.017
ZrO_2	0.00	0.00	0.06
LOI*	1.39	1.10	1.61

III. USE OF FLY ASH IN CONCRETE

One of the efforts to produce more environmentally friendly concrete is to reduce the use of OPC by partially replacing the amount of cement in concrete with by-products materials such as fly ash. As a cement replacement, fly ash plays the role of an artificial pozzolan, where its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (CS-H) gel. The spherical shape of fly ash often helps to improve the workability of the fresh concrete, while its small particle size also plays as filler of voids in the concrete, hence to produce dense and durable concrete.

An important achievement in the use of fly ash in concrete is the development of high volume fly ash (HVFA) concrete that successfully replaces the use of OPC in concrete up to 60% and yet possesses excellent mechanical properties with enhanced durability performance. HVFA concrete has been proved to be more durable and resource-efficient than the OPC concrete (Malhotra 2002). The HVFA technology has been put into practice, for example the construction of roads in India, which implemented 50% OPC replacement by the fly ash (Desai 2004).

IV. MATERIALS

Cement: Cement is a fine, grey powder. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulphate (which controls the set time) and up to 5% minor constituents It is mixed with coarse aggregates, fine aggregates and water to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. It is a material with adhesive and cohesive properties which is capable of bonding mineral fragments into a compact-solid. The ordinary Portland cement (OPC) is the most important type of cement. The OPC is classified into three grades: 33, 43and 53, depending upon the compressive strength of cement at 28 days. Ambuja 43 grade OPC was used in this study. It was fresh and free from any lumps and the specific gravity of cement was 3.17.

Coarse aggregates: Materials retained on 4.75 mm IS sieve and which contain only that much of fine material as is permitted by the specifications are termed as coarse aggregates. The graded coarse aggregate is described by its nominal size i.e. 40 mm, 20 mm, 16 mm and 10 mm. Crushed stone aggregate (locally available) of nominal size 20 mm and 10 mm in the proportion of 50:50 were used throughout the experimental study. The aggregates were washed to remove dust and dirt and are dried to surface dry condition.

Fine aggregate: Aggregates passing through 4.75mm sieve are considered as fine aggregates. Sand is generally considered to have a lower size limit of about 0.07 mm. According to size the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones. The grading zones become finer from grading zone I to grading zone IV. The sand confirming to zone II is used in this study and its specific gravity was 2.59.

Water Fresh potable water, which is free from concentration of acid and organic substances, was used for mixing of concrete.

Metakaolin: Metakaolin (MK) is a pozzolanic material. It is a dehydroxylated form of the clay mineral kaolinite. It is obtained by calcination of kaolinitic clay at a temperature between 500^{0}C and 800^{0}C. Between 100 and 200^{0}C, clay minerals loose most of their adsorbed water. Between 500^{0}C and 800^{0}C, kaolinite becomes calcined by losing water through dehydroxilization. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolinite is the mineralogical term that is applicable to kaolin clays. The dehydroxilization of kaolin to metakaolin is an endothermic process due to the large amount of energy required to remove the chemically bonded hydroxyl ions. Above this temperature range, kaolinite becomes metakaolin, with a two dimensional order in crystal structure.

Polypropylene: fibre Polypropylene is a synthetic hydrocarbon polymer, the fibre of which is made using extrusion processes by hot-drawing the material through a die. Polypropylene fibres are produced as continuous mono-filaments, with circular cross section that can be chopped to required lengths.The function of the polypropylene fibre mixed into concrete is not to replace the steel but to avoid the creation of micro cracks in the concrete.

Fly ash: The fly ash, also known as pulverised fuel ash, is produced from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber along with exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. It is a fine grained powdery particulate material that is collected from the exhaust gases by electrostatic precipitators or bag filters. Depending upon the collection system, approximately 85–99% of the ash from the flue gases in retrieved in the form of fly ash. Fly ash accounts for 75–85% of the total coal ash, and the remainder is collected as bottom ash or boiler slag.

Superplasticizer: Superplasticizers, also known as high range water reducers, are chemicals used as admixtures. These polymers are used as dispersants to avoid particle aggregation, and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. Indeed the strength of concrete increase, whenever the amount of water used for the mix decreases.

V. TESTING OF SPECIMEN

1 Compressive strength: For each mix, totally nine number of cubes of size150mm were cast and tested using 200T capacity compression Testing Machine (CTM). The specimen was placed on the platform of the compression testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the compressive strength of corresponding specimen. .

2.Tensile Strength: For each mix, totally nine number of cylinders of size 300 x 600 mm were cast and tested using 100T capacity compression Testing Machine (CTM). The specimen was placed perpendicular to normal axis on the platform of the compression testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the tensile strength of corresponding specimen.

3. Flexural Strength: For each mix, totally nine number of prism of size 100 x 100 x 500 mm were cast and tested using 5T capacity Flexural Testing Machine (FTM). The specimen was placed perpendicular to normal axis on the platform of the flexural testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the flexural strength of corresponding specimen.

VI. CONCLUSION

In summary, a comprehensive literature review was performed in order to gain a better insight into the key issues relevant Strengthening of Cement Concrete using Fly ash & Metakolin. In the study, These materials have been substantially reduced the cement content and added strength much more that the prior situation. Moreover, it has made cement manufacture cheap and more eco-friendly. The present analysis suggests that the cement content has certainly enhanced the compressive strength of concrete in all the three situations of testing including strength after 7, 14, 28 days respectively which has been taken into account. This is the entire summary which depicts the enhancement in the strength form the rest of the days. Although, in these experiments all the these permutations have been followed, yet it can be hereby concluded that, the overall strength of mere presence of microsilica is more that the addition of fly-ash.

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