Evaluation of Metakaolin for use in Concrete

Dr Deepa A Sinha[1]
[1]Associate Professor, [1]Structural Engineering Dept.
[1]BVM Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India

Abstract--- Extensive research work for decades also is in progress throughout the globe in concrete technology in finding alternative materials which can partially or fully replace ordinary Portland cement (OPC) and which can also meet the requirements of strength and durability aspects. Amongst the many alternative materials tried as partial cement replacement materials, the strength, workability and durability performance of industrial by products like flyash, blast furnace slag, silica fume, metakaolin, rice husk ash, etc., now termed as complimentary cementitious materials (CCM) are quite promising. In this paper the evaluation of Metakaolin for use in Concrete is done.
Keywords: Supplementary cementing material, Engineering properties, Mechanical properties, Durability properties

I. INTRODUCTION

Metakaolin (MK) is a pozzolanic material. It is obtained by calcination of kaolinitic clay at a temperature between 500°C and 800°C. The raw material input in the manufacture of metakaolin ($Al_2Si_2O_7$) is kaolin clay. 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. Kaolinite is defined as a common mineral, hydrated aluminium disilicate, the most common constituent of kaolin. The Meta prefix in the term is used to denote change. In the case of metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time.

The behaviour of clay minerals on heating depends on their structure, crystal size and degree of crystallinity. At just above 100°C, clay minerals lose most of their adsorbed water. The temperature at which kaolinite loses water by dehydroxilization is in the range of 500-800°C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two-dimensional order in the crystal structure and the product is termed metakaolin. The key in producing metakaolin for use as a supplementary cementing material, or pozzolans is to achieve as near as possible complete dehydroxylization without over-heating. Successful processing of kaolinite results in a disordered, amorphous state, which is highly pozzolanic. Thermal exposure beyond a defined point will result in sintering and the formation of mullite, which is dead burnt and not reactive. In other words, kaolinite, to be optimally altered to a metakaolin state, requires that it is thoroughly roasted but never burnt.

Metakaolin is a silica-based product that, on reaction with $Ca(OH)_2$, produces CSH gel at ambient temperature. Metakaolin also contains alumina that reacts with CH to produce additional alumina-containing phases, including C_4AH_{13}, C_2ASH_8, and C_3AH_6.

II. GENERAL PROPERTIES

Fig. 1: SEM photo of metakaoilin

Figure 2 Raw metakaolin considered to have twice the reactivity of most other pozzolans, metakaolin is a valuable admixture for concrete/cement applications. Replacing Portland cement with 8%-20% (by weight) metakaolin produces a concrete mix which exhibits favorable engineering properties, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction. The filler effect is immediate, while the effect of pozzolanic reaction occurs between 7 to 14 days.

Fig. 2: Raw metakaolin Physical properties

Metakaolin is 99.9% finer than 16 µm, and has a mean particle size of 3 µm (as measured by MicroTrac laser diffraction granulometer method (www.metakaolin.com) Surface Area=10,000-25,000 m^2/kg. Some physical properties of metakaolin are given in Table 1. [2]

Property	Value
Specific gravity	2.50
Bulk density (g/cm^3)	0.3-0.4
Physical form	Powder
Color	Off-White
GE Brightness	79-82

Table 1: Physical properties of metakaolin (www.metakaolin.com)

III. CHEMICAL COMPOSITION

Major constituents of metakaolin are SiO_2 and Al_2O_3. Typical chemical composition as reported by is given in Table 2 Metakaolin must meet the requirements of ASTM "C 618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete," Class N, with the following modifications as given in Table 3. (2)

Ingredients	% by weight
SiO,	51.52
$A1_20_3$	40.18
Fe_20_3	1.23
CaO	2.0
MgO	0.12
K.O	0.53
$S0_3$	0.0
$Ti0_2$	2.27
Na_20	0.08
L.O.I	2.01

Table 2: Typical chemical composition of metakaolin (Ambroise et al., 1994)

Modified specification requirements Item	Limit
Silicon dioxide ($Si0_2$) plus aluminium oxide (ALO^) plus iron oxide (Fe_2O_3	Min 85%
Available alkalies	Max 1.0%
Loss on Ignition	Max 3.0%
Fineness: amount retained when wet-sieved on 45 |J.m sieve	Max 1.0%
Strength activity index at 7 days (% of control)	85
Increase of drying shrinkage of mortar bars at 28 days	Max 0.03%

Table 3: Requirements of metakaolin (ASTM C 618)

IV. ENGINEERING PROPERTIES

A. *Loss on ignition*

The loss on ignition shall be not more than 3.0 % Bulk density 300gm/litre

B. *Pozzolanic reaction (Hydration reaction mechanism)*

Calcium hydroxide (CH) accounts for up to 25% of the hydrated Portland cement, and calcium hydroxide do not contribute to the concrete's strength or durability. Metakaolin combines with the calcium hydroxide to produce additional cementing compounds, the material responsible for holding concrete together. Less calcium hydroxide and more cementing compounds means stronger concrete.

C. *Very small particle size of MK*

1) Increase packing/decrease "wall effect"
2) Less than a tenth the size of cement particles, able to fill gap spaces formed between cement near surface of aggregate
3) Increased CSH due to secondary CSH
4) Less CH in paste therefore less to fill voids at interface.
5) Increased bond strength between paste and aggregate
6) Less ettringite formed in ITZ due to reduced size and less CH available as a hydration product [1]

D. *Workability*

- Significant reduction in workability
- Extremely high surface area
- Increase in water demand to maintain consistency
- Irregular particle shape, difficult to mix
- Usually requires superplastizer
- Reduces setting time [1]

E. *Mechanical properties*

1) *Compressive strength*

Compressive strength Metakaolin reaction is rapid, significantly increasing compressive strength even at early age, which can allow for earlier release of formwork. Mixes with metakaolin at 8% of the total cementitious materials have produced concrete compressive strength of more than 20% at 1 day, and 40% at 28 days. [1]

2) *Tensile strength*

- Increases with the increase in compressive strength due to direct relation between them.
- Maximum strengths occur at approx. 14 days and remains relatively stable after [1]

3) *Flexural strength*

- Flexural strength increases but not as significant as compressive and tensile strength.
- Increases with increase in MK replacement level and fineness of MK [1]

F. *Durability properties*

1) *Permeability*

- Refined pore structure extremely beneficial in reducing permeability
- Secondary CSH helps refine pore structure
- Reduction in chloride ion concentration and diffusion
- MK pozzolanic reaction hydration products able to bind free chloride ions, introduced in mix water and from environment [1]

2) *Alkali –Silica reaction (ASR)*

- Reduces ASR expansion
- Due to reduction of alkalis and lower pH in pore solution
- Reduced CH means less calcium and hydroxide ions in solution
- Benefits at 10-15% replacement [1]
- Sulfate attack
- Increased resistance to sulfate attack
- Decrease in available CH for sulfate ions to react with
- Less formation of gypsum and ettringite which have a higher volume than the primary hydration products
- Discontinuous and refined pore structure
- Resistance decreases with increasing w/c ratios
- Approx. 10-15% replacement required [1]
- Efflorescence, which appears as a whitish haze on concrete, is caused when calcium hydroxide reacts with carbon dioxide in the atmosphere. Because metakaolin consumes calcium hydroxide, it reduces

efflorescence.

3) Uses of metakaolin

- Metakaolin finds its usage in many aspects of concrete:
- High performance, high strength and lightweight concrete
- Precast concrete for architectural, civil, industrial, and structural purposes
- Fiber cement and ferrocement products
- Glass fiber reinforced concrete
- Mortars, stuccos, repair material, pool plasters
- Improved finishability, color & appearance. [2]

4) Advantages of using metakaolin

- Increased compressive and flexural strengths
- Reduced permeability
- Increased resistance to chemical attack
- Increased durability
- Reduced effects of alkali-silica reactivity (ASR)
- Reduced shrinkage due to particle packing, making concrete denser
- Enhanced workability and finishing of concrete
- Reduced potential for efflorescence. [2]

V. CONCLUSION

Thus it can be concluded looking to the above properties that metakaolin can be used as a supplementary cementitous material.

REFERENCES

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