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REVIEW ARTICLE

Metakaolin inclusion: Effect on mechanical properties of concrete

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Abstract

Nowadays there is an increasing trend of utilization of waste/non-conventional materials in cement and concrete matrices. These materials are often used as a part replacement of cement reducing the cost of construction and help to overcome the deficiencies associated with the use of Ordinary Portland Cement (OPC) alone. Also, 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. Metakaolin inclusion increases the compressive, tensile, flexural and bend strength and modulus of elasticity of concrete considerably; however, the workability is slightly compromised. This paper presents the review of investigations carried out to find the suitability of metakaolin in production of concrete.

Keywords: Cement, concrete matrices, metakaolin, ordinary portland cement, bend strength.

Introduction

The use of cement replacing materials (CRMs) is fundamental 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 addition of some pozzolanic materials, the various properties of concrete viz., 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 (Sabir *et al.,* 2001; Rojas and Cabrea, 2002; Antonovich and Goberis, 2003).

In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolanic effect depends not only on the pozzolanic reaction, but also on the physical or filler effect of the smaller particles in the mixture.

Therefore, the addition of pozzolanas to OPC increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste. Metakaolin is a pozzolanic material which is manufactured from selected kaolins, after refinement and calcination under specific conditions. It is a highly efficient pozzolona and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicate hydrates (Luc *et al.,* 2003). It is quite useful for improving concrete quality, by enhancing strength and reducing setting time, and may thus prove to be a promising material for manufacturing high performance concrete (Li and Ding, 2003). Metakaolin may be used as a CRM in concrete to reduce cement consumption, to increase strength and the rate of strength gain, to decrease permeability and to improve durability (Khatib and Wild, 1998; Aquino *et al.,* 2001; Asbridge *et al.,* 2001; Boddy *et al.,* 2001; Justice, *et al.,* 2005). In this paper, the influence of metakaolin on mechanical properties of concrete is reviewed.

Properties of metakaolin

Metakaolin is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicate hydrates. The physical and chemical properties of metakaolin viz-a-viz, OPC are presented in Table 1.

Table 1. Physical and chemical properties of cement and metakaolin.

Property	Cement (OPC)	Metakaolin
Specific gravity	3.1	2.5
Mean grain size (µm)	22.5	2.54
Specific area (cm^2/g)	3250	150000-180000
Colour	Dark grey	Ivory to cream
Chemical compositions (%)		
Silicon dioxide ($Si0_9$)	20.25	60-65
Aluminium oxide ($A1_20_3$)	5.04	30-34
Iron oxide (Fe_20_3)	3.16	1.00
Calcium oxide (CaO)	63.61	0.2-0.8
Magnesium oxide (MgO)	4.56	0.2-0.8
Sodium oxide (Na_20)	0.08	0.5-1.2
Potassium oxide (K_2O)	0.51	-
Loss on ignition	3.12	<1.4

Source: Vikas Srivastava *et al.* (2012)

Properties of metakaolin concrete (MKC)

Metakaolin is quite useful for improving concrete quality, by enhancing strength and reducing setting time, and may thus prove to be a promising material for manufacturing high performance concrete. The important properties of metakaolin concrete (MKC) in green and hardened states are presented below.

Workability

The property of concrete which determines the amount of useful internal work necessary to produce full compaction is known as workability. The workability of fresh concrete depends mainly on the material, mix proportion and environmental conditions. In general, workability of concrete decreases on inclusion of metakaolin and decrease in workability increase with the replacement level. Wild *et al.* (1996) reported that workability of concrete at 0.45 water cement (w/c) decrease with increase in replacement of cement by metakaolin. It is found that slump loss was in the range of 2 mm–32 mm when replacement level of cement was in the range of 5%-35%. Justice and Kurtis (2007) reported that workability decreased with increasing metakaolin surface area. They also reported that at 0.40 w/c, the dose of super plasticizer required was double for metakaolin concrete (8%) as compared to control concrete. Dubey and Banthia (1998) reported that on inclusion of 10% high reactive metakaolin (HRM), slump loss of 20 mm was observed as compared to control concrete. Quian and Li (2001) reported that for concrete with 1% super plasticizer addition, the slump progressively decreased with increasing metakaolin content. However, by increasing the super plasticizer dose to 1.2%, the slump showed only minor variation with increasing metakaolin content. Wong and Razak (2005) reported that at 0.33 w/c slump value decreases with increase in replacement of cement by metakaolin. Slump value reported as 240 mm, 225 mm, 195 mm and 155 mm at 0%, 5%, 10% and 15% replacement of metakaolin respectively.

Compressive strength

Wild *et al.* (1996) reported that on inclusion of metakaolin upto 30%, compressive strength at 28 d increase in the range of 1.53%-35%. However, maximum increase is reported at 20% replacement level. It is found that on inclusion of metakaolin compressive strength is increased. Increase in compressive strength is found in the range of 9.82%-38.72% when replacement level of metakaolin was 11-35%. However, maximum increase in compressive strength was at 15% replacement level. Justice and Kurtis (2007) reported that increased compressive strength by 15-50% (depending on metakaolin type, w/c and age) as compared to control mixture was measured for concretes produced with metakaolin.

The higher surface area metakaolin yielded the highest strength and the fastest rate of strength gain. The positive influence of the metakaolin fineness on compressive strength was more apparent at the later ages (i.e. 7 d or more). Dubey and Banthia (1998) reported that on inclusion of 10% high reactivity metakaolin (HRM), compressive strength increased by 9.10% at 28 d. Quian and Li (2001) reported that the compressive strength increases substantially with increase in metakaolin content. Especially at 3 d curing it increases 51% at 15% metakaolin relative to concrete without metakaolin. Furthermore, the 3 d strength at 10% and 15% metakaolin replacement are large than the 28 d strength without metakaolin, confirming that metakaolin has a pronounced influence on early strength.

Tensile strength
Splitting tensile strength of concrete incorporating metakaolin is similar to that observed in concretes without metakaolin. As the compressive strength increases the tensile strength also increases. Quian and Li (2001) reported that the tensile strength of concrete increases systematically with increasing metakaolin replacement level. The tensile strength increase reported as 7% (5% metakaolin), 16% (10% metakaolin) and 28% (15% metakaolin) at 28 d.

Flexural strength
Flexural strength of concrete incorporating metakaolin is similar to that observed in concretes without metakaolin. Justice and Kurtis (2007) reported that flexural strength measured in 4 points loading was increased by 20-40% at 8% metakaolin. They also reported that strength attained by metakaolin concrete at 1 d was equal to the strength attained by control concrete at 3 d and strength attained by metakaolin concrete at 3 d was equal to the strength attained by control concrete at 28 d. Dubey and Banthia (1998) reported that on inclusion of 10%, high reactive metakaolin (HRM), flexural strength increased by 9.11% at 28 d. It is also reported that the flexural toughness factor for HRM concrete was about 9% greater than the nonpozzolanic, control concrete, 21% greater than the silica fume concrete and about 10% higher than the hybrid-pozzolanic concrete.

Bond strength
Quian and Li (2001) reported that a metakaolin replacement level of 5% has little effect on the bend strength of the concrete. At 10% and 15% replacement, the 28 d bend strength increased by 32 and 38% respectively in relation to that without metakaolin.

Modulus of elasticity
Justice and Kurtis (2007) reported that by inclusion of 8% metakaolin, increase in elastic modulus by 5-19% as compared to control concrete is observed.

Conclusion
The following conclusions are drawn on the use of metakaolin in concrete making:

1. Metakaolin reduces workability. However, in certain cases with appropriate doses of plasticizers the effect is not much.
2. The gain in compressive strength is improved depending upon the replacement level of OPC by metakaolin.
3. The metakaolin inclusion generally improves tensile strength, flexural strength, bond strength and modulus of elasticity. The quantum of increase in the individual properties depends upon replacement level.

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