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Strength properties and durability aspects of high strength concrete using Korean metakaolin

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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 remained 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 silica fume 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.

Keywords: Metakaolin; Silica fume; Durability; Permeability; Freezing and thawing; Carbonation; Chemical attack

1. Introduction

Recently, the diversification of structures emphasized the interest on the workability and durability of concrete resulting from the growing necessity to provide high performance concretes exhibiting high strength and high durability.

Representative admixtures that have been developed to date are fly ash, silica fume, blast furnace slag, etc. In most cases, mortars and concrete containing these materials with pozzolanic or latent hydraulic characteristics have mechanical properties and durability superior to that of OPC concrete [1–4].

In the last years, metakaolin (MK) has been introduced as a highly active and effective pozzolan for the partial replacement of cement in concrete. It is an ultra-fine material produced by the dehydroxylation of a kaoline precursor upon heating in the temperature range of 700–800 °C [5] and has high pozzolanic properties [6,7].

In general, among the supplementary cementitious materials, the remarkable performances exhibited by concrete mixed with silica fume in terms of strength and dura-

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bility favored its active exploitation where high strength or durable concrete were required.

In Korea, however, the increase of construction costs due to the increasing price of imported silica fume compared to other admixtures led researchers to turn their interest toward metakaolin, an economical and promising cementitious material presenting similar strengthening effects as silica fume. Recent research trends focused essentially on the basic material and mechanical properties of metakaolin. With the intention to supplement these researches, the approach adopted in this study gives larger consideration on the fabrication and application aspects of high durability and high performance concrete.

Therefore, this paper intends to verify the applicability of metakaolin in the fabrication of high-performance concrete exhibiting high strength and high durability through the experimental observation of the strength characteristics, resistance to salt attack and carbonation of concrete using metakaolin.

2. Experimental details

2.1. Materials

Ordinary Portland cement, silica fume (SF), metakaolin (MK) and fly ash (FA) were used as binder. The chemical and physical properties of these are summarized in Table 1. Washed sand was adopted for fine aggregate, and crushed stone with maximum size of 20 mm was used as coarse aggregate. The high range AE water reduction agent based on the salt of a polymetric naphthalene sulphonate was also introduced as chemical admixture.

2.2. Test series 1

The purpose of the first test series is to compare the fundamental properties of metakaolin with those of silica fume. To examine the crystallography of the binder materials X-ray diffraction analysis was conducted and to observe the hydrated products instrumental analyses like SEM and EDS and X-ray diffraction method were carried out at 56 days for paste samples with water to binder ratio (W/B) of 0.5 when the replacement levels of the weight of cement were 0%, 5%, 10%, 15% and 20%.

On the other hand, the flow value of mortars containing metakaolin or silica fume were evaluated. The mixture proportion of all mortars was binder/sand = 1:2.5 and water to binder ratio (W/B) of 0.5. Mortar mixtures were mixed with metakaolin or silica fume mixed at 0%, 5%, 10%, and 15% of the weight of cement without any chemical admixture.

2.3. Test series 2

The purpose of the second test series is to compare the strength properties and thermal characteristics of concrete containing metakaolin or silica fume with fly ash for high strength concrete. Table 2 lists the mix proportions of concrete defined to have design strength of 60 MPa, slump flow of 50 ± 5.0 cm, air content of $3.0 \pm 1.0\%$, and water to binder ratio (W/B) of 0.25. All the mix proportions of concrete were done so as to replace 20% of the weight of binder by fly ash taking account of high heat of hydration of high binder content. Nine mix proportions were manufactured with metakaolin and silica fume mixed at 0%, 5%, 10%, 15% and 20% of the weight of binder.

Table 1
Chemical and physical properties of binder

	Composition (%)							Specific gravity	Surface area (cm^2/g)	Appearance
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	$Na_2O + K_2O$			
OPC	21.95	6.59	2.81	–	60.1	3.32	–	3.15	3112	Gray
FA	66.65	22.98	1.92	–	1.61	0.87	–	2.20	4258	Gray
MK	56	37	2.4	0.2	2.4	0.3	0.9	2.63	120,000	Light pink
SF	94.0	0.3	0.8	–	0.3	0.4	1.0	2.20	200,000	Gray

Table 2
Mix proportions of concrete in test series 2

	W/B (%)	s/a (%)	Unit weight (kg/m^3)						
			Cementitious materials				Water	Fine aggregate	Coarse aggregate
			Cement	FA	MK	SF			
Control	25	37	563	141			176	532	915
MK05	25	37	528	141	35	–	176	529	909
MK10	25	37	493	141	70	–	176	525	903
MK15	25	37	458	141	106	–	176	522	897
MK20	25	37	422	141	141	–	176	518	891
SF05	25	37	528	141	–	35	176	530	911
SF10	25	37	493	141	–	70	176	528	908
SF15	25	37	458	141	–	106	176	526	904
SF20	25	37	422	141	–	141	176	524	900