COMPARATIVE STUDY OF METAKAOLIN AND SILICA FUME TO PREVENT ALKALI-SILICA REACTION IN CONCRETE

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Abstract

This paper presents the results of comparative study of two well-known pozzolanic materials; metakaolin (MK) and silica fume (SF), to control the extent of deleterious alkali-silica reactions in concrete. While application of pozzolanic materials is known to be beneficial in preventing ASR, few data are available on Iranian concrete practices.

Derived from purified kaolin clay, metakaolin is a white, amorphous, alumina-silicate which reacts readily with calcium hydroxide and significantly controls ASR. Silica fume would be highly effective in controlling the alkali aggregate reaction due to its high silica content and high surface area.

In this study the effect of different replacement levels of metakaolin and silica fume on ASR potential is investigated by means of accelerated mortar bar test (AMBT). Results are discussed in a comparative base, from the view points of ASR potential, and the effect of SF and MK to control the reactions.

Keywords: concrete, metakaolin, silica fume, deleterious ASR, prevention

1 INTRODUCTION

Worldwide demand for high performance concrete is increased in recent decades. Alkali-silica reaction (ASR) has become one of the most challenging problems affecting durability performance of concrete structures today.

Pozzolanic materials play an important role in developing the microstructure of concrete via pozzolanic reactions and due to fineness of particles. Fly ash and silica fume are well known to engineers for decades and are vastly used in many concrete projects worldwide.

In recent years, there has been an increasing interest in the utilization of metakaolin in concrete as a partial substitution for cement in high performance concrete. Commercially available since the mid-1990s, high reactivity metakaolin is developed for high performance concrete application. Bonakdar et al. [1] reported that high reactivity metakaolin is mostly manufactured by hydro-calcination of raw kaolinite at the temperature range of 700-900 ˚C and contains high percentages of SiO_2 and Al_2O_3. Ding and Li [2] showed that the quick consumption of CH and the increase in the CSH and hydrated gehlenite (C_2ASH_8) lead to refinement of the pore structure, which was considered the principal mechanism for improvement of concrete properties by the addition of metakaolin. Properties of concrete containing metakaolin at different substitutions have been studied by many researchers in recent years, from which noticeable results have been issued.

In this study the efficacy of commercial grade of metakaolin in controlling the expansion due to ASR is evaluated according to new standard test method, ASTM C 1567 [3], which permits detection within 16 days of the potential for deleterious alkali-silica reaction of combinations of cementitious materials (hydraulic cement, pozzolans and ground granulated blast furnace slag) and aggregate in mortar bars.

2 MATERIALS

The cement used in this study was an ordinary Portland cement (Type II) provided from Tehran Cement Company. Silica fume is obtained from Azna Ferro-silicon alloy manufacture, Iran. metakaolin was provided from Asan Seram Company, Iran. The chemical compositions of metakaolin, silica fume and Portland cement are shown in Table 1.

Igneous rocks from Aras region, Iran were used as reactive aggregates. Petrographic examination reveals potential alkali reactivity of these aggregate materials due to presence of chert and metastable silica.

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3 EXPERIMENTAL METHODS

3.1 General

Six different mortar mixes were prepared as shown in Table 2. Aggregate grading and mix proportions for all mixes were selected in accordance with ASTM C1567. The water to binder ratio was kept 0.47 by mass and the amount of high range water reducer (HRWR) was set to obtain a flow of ±7.5 percentage points of a control mortar without silica fume or metakaolin as determined in accordance with Test Method C1437 [4] using 25 drops of the flow table. Mortar bars were studied for length change in a period of 28 days after casting.

3.2 Accelerated mortar bar test (AMBT)

The accelerated mortar bar test according to ASTM C1260 [5] which was originally proposed by Oberholster and Davies in 1986 is the most widely used accelerated method for the potential alkali-silica reactivity of concrete aggregates [6].

Soon after development of the AMBT, it was proposed that it might also be a useful tool for evaluating the efficiency of pozzolans for controlling expansion. The AMBT can be used to evaluate preventive measures using newly modified version of ASTM C 1260 published in 2004 as ASTM C 1567[7].

The mixing and moulding procedures followed the requirements of ASTM C 1567. The bars were demoulded after 24 h and placed into a water bath at room temperature then heated to 80 °C as specified in the test method. The bars were cured for 1 day, and then immersed in 1 N NaOH solution at 80 °C after the initial (zero-day) length measurement. The expansions were recorded at 1, 3, 7, 10, 14, 21, 28, days.

4 RESULTS

Expansion result of the mortars according to ASTM C1567 is presented in Table 3 and Figure 1. Effect of MK and SF replacement on expansion at different ages is shown in Figure 2 and 3.

5 DISCUSSION

As stated in recommendation mentioned in ASTM C 1567, aggregates used in specimens which have expansion of less than 0.1% after 14 days exposure to 1-N NaOH solution are likely to have a low risk of deleterious expansion when used in concrete. According to the expansion results of control mix and critical limits mentioned in ASTM C 1567 as expected, fine aggregates show high potential of alkali-silica reactions. Control mix expanded at a fast rate, and reached expansion magnitude of 0.21% and 0.33% at 14 and 28 days respectively.

Similar to the results of Walters and Jones [8], In general, SF and MK decrease the expansion in a same manner. Although 5% replacement level for SF and MK do not satisfy the safety factors mentioned in ASTM C 1567 as both of them result in an expansion of 0.1-0.2% at 14 days.

Increasing the replacement level of both SF and MK from 5 to 10 % by weight of cementitious materials will reduce the expansion significantly, while this reducing trend is less considerable from 10 to 15%. Similar results were reported by Gruber et al. [9] in the past for this difference of rate between MK5 and MK10.

It can be seen from the results that MK15 and SF10 present a similar behaviour at the age of 14 days. But after 14 days, the expansion rate of MK15 seems to be less than the SF10. Aquino et al. [10] also report this trait in the comparison of MK and SF.

6 CONCLUSIONS

The aim of this study was to investigate the effect of metakaolin in controlling the deleterious expansion due to alkali-silica reaction in comparison with silica fume. Accelerated mortar bar test method was used in order to study the rate and extent of expansions in a period of 28 days.

From the results following conclusions can be drawn out:

a- Metakaolin and silica fume similarly control the expansions due to ASR, although in same replacement levels, silica fume will control the expansions better than metakaolin.

b- Increasing the replacement level from 5 to 10 % by weigh of cementitious materials, will significantly reduce the expansions, while an increase in replacement level from 10-15% will be less effective.

7 REFERENCES

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TABLE 1: Bulk chemical compositions of ordinary Portland cement, metakaolin and silica fume.

	Chemical composition, in wt%									
Species	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Na_2O**	**K_2O**	**L.O.I**	**Total**
Cement	20.03	4.53	3.63	60.25	3.42	2.23	0.35	0.65	5.03	99.12
Metakaolin	51.85	43.87	0.99	0.2	0.18	---	0.01	0.12	0.57	97.79
Silica fume	93.16	1.13	0.72	---	1.60	0.05	---	---	1.58	98.24

TABLE 2: Mix proportions

sample	**fine aggregate**	**binder (OPC)**	**w/c ratio**	**silica fume**	**metakaolin**
	gr	gr		(% of binder)	(% of binder)
C	990	440	0.47	--	--
MK5	990	440	0.47	--	5
MK10	990	440	0.47	--	10
MK15	990	440	0.47	--	15
SF5	990	440	0.47	5	--
SF10	990	440	0.47	10	--

TABLE 3: Expansion of concrete prisms according to ASTM C 1567							
Age (Days)	1	3	7	10	14	21	28
Sample	**expansion of concrete prisms (%)**						
C	0.025	0.038	0.099	0.147	0.207	0.272	0.332
SF5	0.000	0.013	0.042	0.080	0.106	0.161	0.211
SF10	0.000	0.005	0.016	0.019	0.039	0.068	0.075
MK5	0.004	0.019	0.092	0.133	0.192	0.258	0.306
MK10	0.017	0.020	0.038	0.046	0.048	0.065	0.088
MK15	0.015	0.016	0.028	0.036	0.039	0.047	0.058

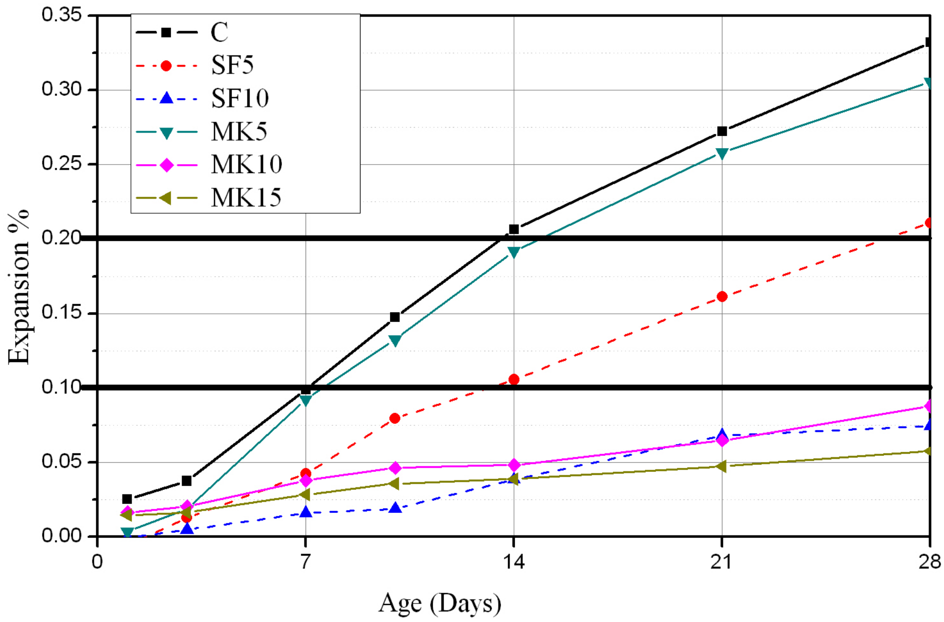

Figure 1- Expansion of mortar bars according to ASTM C 1567

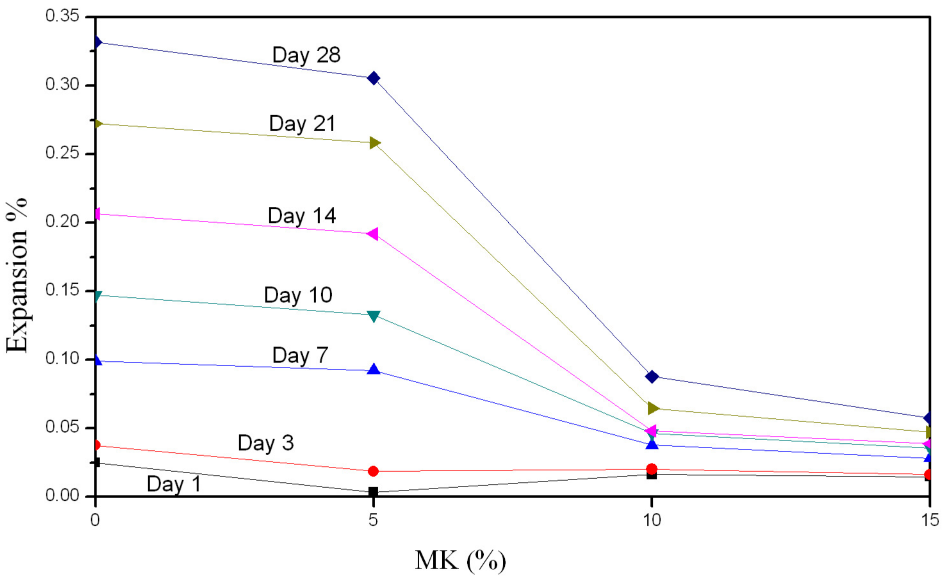

Figure 2- Effect of amount of metakaolin replacement on expansion at different ages

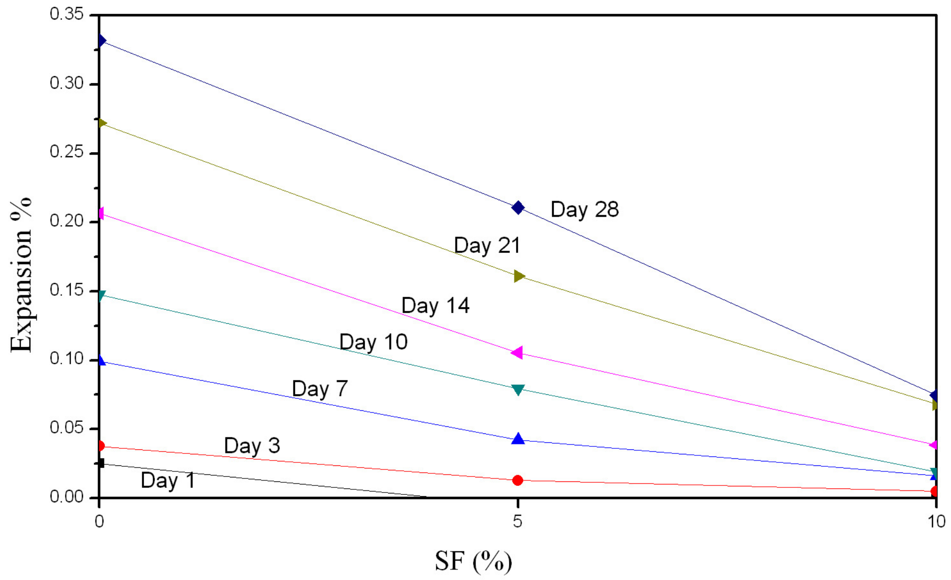

Figure 3- Effect of amount of silica fume replacement on expansion at different ages