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EFFECTS OF FINELY GROUND SILICA, SILICA FUME AND RED MUD ON ALKALI–SILICA REACTION AND CONCRETE STRENGTH

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Synopsis: The effects of finely ground silica, silica fume and red mud on alkali-silica reaction and compressive strength were investigated in order to use these admixtures on mortar and concrete.

The results of testing were that the use of an admixture consisting of finely ground silica or silica fume and red mud, each as a substitution of 5 percent per cement content, decreased the expansion of mortar bar due to alkali-silica reaction; and was effective in improving the compressive strength of concrete.

Keywords: finely ground silica; silica fume; red mud; alkali-silica reaction; expansion of mortar bar; compressive strength.

1. INTRODUCTION

Recently, finely ground silica having superhigh fineness has been developed as a replacement material for silica fume, in Japan. As the costs of finely ground silica and silica fume have become much more expensive than ordinary Portland cement, there has been some discussion as to whether to use these siliceous materials together with the red mud of a low cost by-product. There are few reports on red mud as yet [1],[2].

As sodium oxide accounts for about 9 percent of red mud, the effect of finely ground silica or silica fume and red mud on alkali-silica reaction was investigated by a mortar-bar method using reactive and non-reactive aggregates. The compressive strength of concrete was then tested, using different mixing ratios of siliceous material and red mud with 10 percent substitution of cement content.

2. EFFECT ON ALKALI-SILICA REACTION

2.1 Admixtures, Cement and Aggregates Used

Finely ground silica (abbreviated as FGS) was made by grinding natural siliceous clay with a ball mill to the specific surface area of 12 m^2/g. Silica fume (abbreviated as SF) was obtained from the dust-collector of a ferro-silicon plant in Kochi City. Red mud (abbreviated as RM) was a by-product from alumina production at a chemical factory in Niihama City. The main chemical compositions and physical properties of these admixtures compared with cement are shown in Table 1.

Table 1. Main Chemical Compositions and Physical Properties of Admixtures and Cement Used

Materials used	Chemical compositions (%)						Physical properties	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	ig. loss	Specific gravity	Specific surface area (m^2/g)
Finely ground silica	86.9	2.52	1.24	0.77	0.04	6.34	2.27	12.0 **
Silica fume	81.3	1.20	2.94	1.56	0.47	5.80	2.35	16.3 **
Red mud	15.2	20.27	38.80	0.09	8.94	10.49	3.35	21.5 **
Ordinary P. cement *	21.9	5.20	2.90	63.80	0.44	1.10	3.15	0.313 ***

* $Na_2O + 0.658K_2O = 0.78\%$ ** BET method *** Blaine's method

Ordinary Portland cement was used. The alkali content of the cement was controlled by the addition of sodium hydrate.

Pyrex glass and augite andesite were used as reactive aggregates and crushed diabase was used as a typical non-reactive aggregate. The main physical properties and the test results of the chemical method specified according to ASTM C289 are shown in Fig. 1.

Each coarse aggregate was crushed to sand size, and fine aggregate was prepared to a grading meeting the requirement of the specification on mortar bar method (ASTM C227-81).

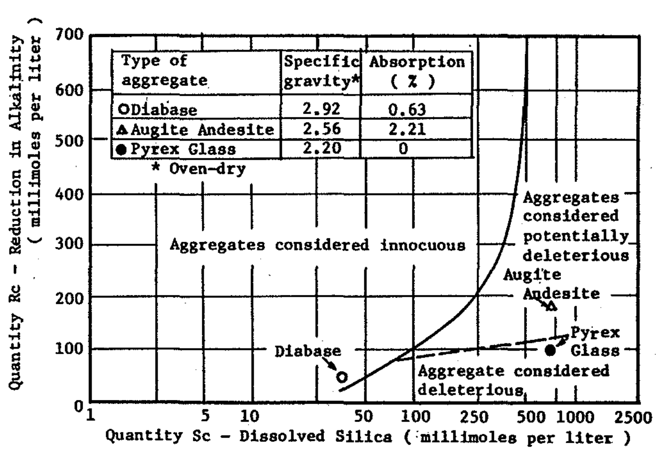

Fig. 1. Illustration of Test Results of Aggregates according to Chemical Method (ASTM C289-81)

2.2 Outline of Testing Procedures

The following three test series were performed to investigate the effect of admixtures on the expansion of mortars due to alkali-silica reaction.

(1) The effect of the admixture consisting of FGS or SF and RM on the expansion of mortar bars containing reactive aggregate.

(2) The effect of RM content on the expansion of mortar bar containing non-reactive aggregate.

(3) The effect of the cement aggregate ratio of mixture on the expansion of mortar bar containing non-reactive aggregate.

The mortar mixture used are shown in Table 2.

Mortar specimens were fabricated and cured according to ASTM C227.

The expansion of specimens after 14 days (2 weeks) was measured for each mortar bar of 25x25x285 mm size by a dial-gauge method.

The test ages of specimens were 2, 4, 8, 13 weeks (3 months) and 6 months.

Table 2. Mixture Proportions of Mortars Used

Series	Mix. No.	Aggregate (g)	Cement** (g)	Admix. (g)	Constituent (%) FSG	SF	RM	Alkali* content (%)
(1) FGS or SF and RM	1	Pyrex Glass 675g	300	0	0	0	0	1.0
	2		270	30	5	0	5	1.0
	3		270	30	0	5	5	1.0
	4	Augite Andesite 675g	300	0	0	0	0	1.2
	5		285	15	0	0	5	1.2
	6		270	30	5	0	5	1.2
	7		270	30	2.5	0	7.5	1.2
	8		270	30	0	5	5	1.2
	9		270	30	0	2.5	7.5	1.2
(2) RM	10	Diabase 675g	300	0	0	0	0	0.78
	11		285	15	0	0	5	0.78
	12		270	30	0	0	10	0.78
	13		255	45	0	0	15	0.78
	14		300	0	0	0	0	1.2
	15		270	30	0	0	10	1.2
(3) C:A ratio	16	Diabase 1800g	500	0	0	0	0	0.78
	17		450	50	0	0	10	0.78
	18		450	50	5	0	5	0.78
	19		450	50	0	5	5	0.78

* 1.0 and 1.2% are controlled in addition of NaOH
**Water cement (cementing material) ratio was 50%

2.3 Test Results and Some Considerations

2.3.1 Effect of FGS, SF and RM on reactive aggregates As can be seen in Fig. 2 and Fig. 3, the expansion of mortar using FGS or SF and RM decreases compared with that of plain mortar without admixture for both pyrex glass and augite andesite. This indicates an inhibition effect on the expansion of siliceous admixtures, as the mortar using only 5 percent RM yields a higher expansion compared to that of plain mortar in the mixture of augite andesite (see Fig. 3).

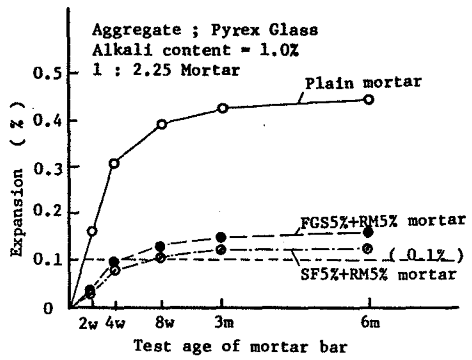

Fig. 2. Effect of Admixtures on Expansion of Mortar Bar Using Pyrex Glass

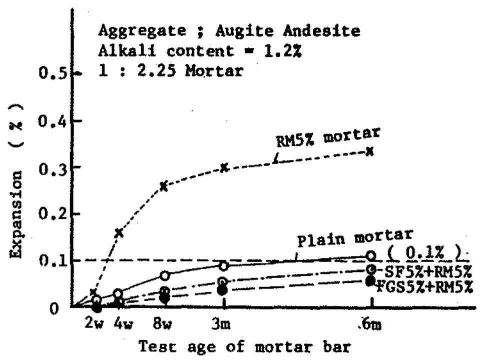

Fig. 3. Effect of Admixtures on Expansion of Mortar Bar Using Augite Andesite

The existence of a considerable number of white spots due to alkali-silica reaction was observed on the surfaces of mortar specimens containing reactive aggregates at the greater age of 6 months. These phenomena were most noticeable on the plain mortar bars containing pyrex glass, and the surface color was whitish on the whole.

Perry et al [3] and Asgeirssion [4] reported that the use of silica fume could reduce the expansion of mortar bar. On the other hand, Kawamura and Hasaba [5] pointed out that the degree of prevention was different according to the type of silica fume. It is considered that siliceous materials of a high quality are effective for the reduction of the expansion of mortar and concrete.

2.3.2 Effect of RM on non-reactive aggregate Although the expansion of mortar bar using the diabase of non-reactive aggregate clearly increases with the increment of RM, its extent after a period of 6 months is 0.04 percent in the mortar using 5 percent RM as are shown in Fig. 4. When the alkali content of cement increases from 0.78 to 1.20 percent, the expansion of mortar containing RM becomes higher.

The addition of RM for mortar tends to increase the expansion of mortar bar in the case of non-reactive aggregate also, however the 6-month expansion falls under the requirement of the specification according to ASTM C227, being within the limit of 15 percent RM content.

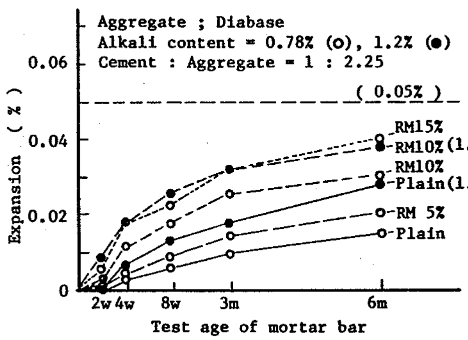

Fig. 4. Effect of Red Mud on Expansion of Mortar Bar Using Diabase

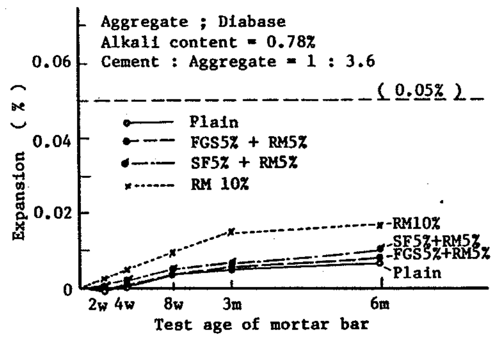

Fig. 5. Expansion of Mortar Bar Using a Mixture of Cement Aggregate Ratio, 1 : 3.6

2.3.3 Effect of cement aggregate ratio The expansion of mortar having a cement aggregate ratio of 1 to 3.6 decreases more clearly than that of 1 to 2.25, and the 6-month expansion of the former is less than 0.02 percent in the poor mixture of mortar (see Fig. 5). It was reported that the cement content had a great influence on the expansion of concrete [6]. The use of poor mixture is effective to reduce the expansion of mortar.

3. EFFECT ON COMPRESSIVE STRENGTH OF CONCRETE

3.1 Materials Used and Mixture Proportions of Concretes

Ordinary Portland cement (ρc = 3.15) was used. Crushed silicic stone (ρg = 2.77, absorption = 0.70 %) with a maximum size of 15 mm was used as a coarse aggregate. Both crushed silicic sand of 5 to 2.5 mm and sea sand (ρs = 2.72, absorption = 1.30 %) were used as fine aggregate having a fineness modulus of 2.65.

FGS, SF and RM used are shown in Table 1. Also, a high-range water reducing agent consisting of naphthalen sulfate was used as a chemical admixture.

The mixture proportions of concretes used are shown in Table 3. The substitution of admixtures was just 10 percent of cement content, bearing in mind the effect on alkali-aggregate reaction. The mixing ratio of FGS or SF to RM in the admixtures was changed by means of 5 types, namely 10 : 0, 7.5 : 2.5, 5.0 : 5.0, 2.5 : 7.5 and 0 : 10.

Table 3. Mixture Proportions of Concretes Used

Type of mixture	Max. size (mm)	Slump (cm)	Air (%)	W/C (%)	s/a (%)	Water (kg)	Cement (kg)	Admix. (kg)	HRWR agent (%/C)
Plain	15	5 ± 1	(2)	34	50	152	450	0	1.5
Admixture	15	5 ± 1*	(2)	34	50	152	405	45	1.8 - 2.0

* Slump of each concrete using admixtures was controlled by the dosage of HRWR agent.

3.2 Mixing Concrete, Making Specimens and Their Testing

Concrete was mixed by a forced mixing type mixer, and then was placed into a cylinder mold of 10x20 cm size. This was followed by the compaction of concrete for three minutes by means of a table vibrator (3000 vpm in frequency and 0.5 mm in amplitude). Concrete specimens were removed from molds at the next day after placing and they were cured in a water tank of about 20°C for given periods of time.

The compressive strength was tested using a universal testing machine at the ages of 7 days and 28 days. The mean value carried out on three specimens is used.

3.3 Test Results and Some Considerations

As can be seen in Fig. 6, the concrete containing FGS or SF and RM yields considerably higher strength, namely from 23 to 34 percent stronger, than that of plain concrete at the ages of 7 days and 28 days. When the mixing ratio of siliceous material to RM increases within a range of 10 percent, the compressive strength tends to be stronger at the age of 28 days and the concrete containing 10 percent SF gives the highest strength of about 90 MPa. The effect of FGS and RM on the compressive strength of concrete is not so different from that of SF and RM.

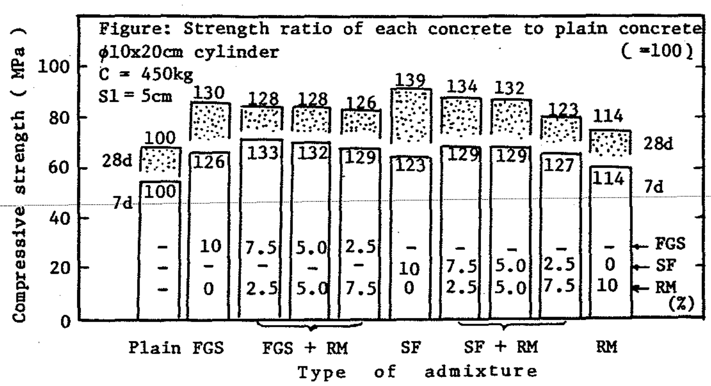

Fig. 6. Compressive Strengths of Concretes Containing Finely Ground Silica, Silica Fume and Red Mud

It is considered that the strength improvement due to the use of these admixtures is caused by the dense concrete structure resulting from the pozzolanic action of high quality silica, the multiplication and microfiller effects [2]. Consequently, these admixtures such as FGS, SF and FM are effective in improving the compressive strength of concrete.

4. CONCLUSIONS

As the results of these investigations, the following conclusions can be stated.

1. The use of finely ground silica or silica fume and red mud decreases the expansion of mortar bar due to alkali-silica reaction.
2. The addition of red mud without siliceous materials increases the expansion of mortar bar.
3. The use of poor mixture is effective to reduce the expansion of mortar bar.
4. The compressive strength of concrete can be improved by the use of finely ground silica or silica fume and red mud.
5. The effect of finely ground silica having a high silica content is almost the same as that of silica fume.

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