AN EXPERIMENTAL STUDY ON ALKALI REACTIVITY OF FERRO-NICKEL SLAG AGGREGATE FOR CONCRETE

Fuminori Tomosawa *
Masahiro Yokoyama **

Four kinds of Ferro-Nickel Slags (FNS) aggregate produced in Japan were tested on the alkali reactivity. When aggregate was manufactured by water granulation from the slag of electric furnace process, it had a tendency of susceptibility. No reactivity has been recognized practically in aggregates manufactured by air cooled or air granulated from electric furnace process or manufactured by water cooled slag from rotary kiln method. The expantion of innocuous FNS aggregates is proportional to the dissolved Silica. Results of investigation on the exposed structures was also mentioned.

INTRODUCTION

Ferro-Nickel Slag (FNS) is one of the major industrial waste materials to be reused in the metal industry. The annual production of FNS now has grown up two million tons. The most possible and appropriate way of its use was considered to be fine aggregate for concrete. The industry has developed manufacturing processes of aggregate from the slag and the used aggregate in some concrete products and private construction works. In the way of research work for the acquisition of the public approval as aggregate for structural concrete, it was pointed out that the aggregate was susceptible of alkali aggregate reaction.

By successive investigations, it was found out that the susceptibility was related to the production process (Yamamoto and Akiyama (1), Morinaga et al (2), Katayama (3)). Outlines of production method of FNS (A,B,C,D) are shown in Table 1.

In this paper, the progress of investigation on this matter was reviewed and alkali reactivity test on several kinds of FNS aggregate mentioned as well as some characteristic points observed in the test. Results of investigation on the existing

*Department of Architecture, Faculty of Engineering, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo, 104 Japan
**Y.S. Engineering Co., Ltd.
8-10, Ginza-nishi, Chuo-ku, Tokyo 104 Japan

structures and exposed specimens. The qualification of FNS aggregate is now being established as Japanese Industrial Standard.

REACTIVITY OF FERRO-NICKEL SLAG

Following experiments on reactivity of FNS aggregate were made:

1. Standard test (JIS A 5308; Chemical and Mortar Bar Method) four kinds of FNS aggregates.

2. Long-term observation of mortar bars used hi-alkali content cement (R_2O=0.7, 1.2, 1.5, 2.0%)

3. Suppressing effects of varying natural sand mixing ratio and characters of cement.

Standard Test

Chemical Method. RC and SC of FNS (A,B,C,D) aggregates were measured according to JIS A 5308 Annex 7. Test Method for Potential Alkali Silica Reactivity of Aggregates (Chemical Method). Test results are shown in Table 7.

Regarding to 'A' aggregates, eight samples were tested, mainly produced at 1991 and 1992.

Regarding to 'B' and 'C', sampled periodically from average run at the same plant, 28 aggregates were tested respectively.

Regarding to 'D' aggregate, four samples were tested.

Test results of Chemical Method are shown in Table 2 and Figure 1. As shown Figure 1, large majority of FNS aggregates were judged not innocurous and only five samples were judged innocurous by Chemical Method. As for 'A' aggregate, the SC and RC was relatively small and the range of values was narrow, mean of RC/SC was 0.81.

Mortar Bar Method. Mortar Bar Method of JIS A 5308, Annex 8. is similar to ASTM Method, excepting alkali-content of used cements. Expantion test results of the aggregates (A,B,C,D) are summerized in Table 2, and effects of Sc, Rc and Sc/Rc on the expantion of the test specimens are shown in Figure 2,3 and 4.

As shown in Table 2, FNS aggregate A and C were judged innocurous, while D aggregate was judged not innocurous by Chemical Method. As evident from Figure 2 and 3, the expantion coefficient of FNS B and C were in proportion to Sc, not to Rc. Regarding to the relationship between Rc/Sc and the expantion of A, B and C aggregate, the relationship was little, apparently from Figure 4.

The equation YB and YC obtained a least squares method shown in Figure 2 are as follows:

TABLE 1 - Production Methods and Properties of FNS Aggregates

F.N.S.	Type of Furnace	Production Method	Size mm	Specific Gravity	Chemical SiO_2	Composition % MgO	CaO	FeO
A	Rotary Kiln	Water cooled & crushed	1.2	3.08	53.5	29.0	5.4	5.9
B	Electric Furnace	Air granulated	5.0	2.86	53.3	35.1	0.5	5.9
C	Electric Furnace	Air cooled & crushed	5.0	3.01	54.2	35.9	0.5	4.7
D	Electric Furnace	Water Granulated	5.0	2.82	52.0	33.6	0.4	9.6

TABLE 2 - Potential Alkali-Silica Reactivity of FNS Aggregate by Chemical and Mortar Bar Method

		Chemical Method								Mortar Bar Method		
		Rc mmol/l				Sc mmol/l				Expantion %		
FNS	n	Mean	Max.	Min.	SD	Mean	Max.	Min.	SD	Mean	Max.	Min.
A	8	42.4	51	32	6.7	52.5	60	45	5.5	0.021	0.028	0.014
B	28	38.5	76	15	29.6	98.2	152	40	29.6	0.037	0.049	0.023
C	28	51.2	84	18	28.2	83.1	135	35	28.2	0.041	0.054	0.031
D	4	68.3	102	44	-	185.8	226	164	-	0.441	0.528	0.356

Note: Max.: Maximum Value, Min.: Minimum Value, SD: Standard Deviation

$$YB = (12.3+0.25xSc) \div 1000 \quad \ldots\ldots\ldots\ldots \quad \%$$

YB: expantion of aggregate B
Numbers of specimens: 28
Correlation factor: 0.769

$$YC = (20.0+0.26xSc) \div 1000 \quad \ldots\ldots\ldots\ldots \quad \%$$

YC: expantion of aggregate C
Numbers of specimens: 28
Correlation factor: 0.767

TABLE 3 – Results of Mortar Bar Test on the Effect of Kinds of Cement and mixing Ratio of Natural Sands on the Expantion of F.N.S. 'D' Aggregate

Test No.	Kind & Mixing Ratio of Sand				Cement		Expantion	Judgement
	FNS'D'	River	Sea	Crushed	Type	R_2O		
1	100	-	-	-	N	1.20	0.402	Not Innocuous
2	80	20	-	-	N	1.20	0.320	
3	60	40	-	-	N	1.20	0.260	
4	40	60	-	-	N	1.20	0.227	
5	40	-	-	60	NL	0.54	0.042	Innocuous
6	60	-	40	-	NL	0.54	0.049	
7	60	-	40	-	FB	0.58	0.031	
8	60	-	40	-	BB	0.40	0.015	
9	-	100	-	-	N	1.20	0.016	

Long-Term and Hi-alkali Test

Four kinds of FNS aggregate were investigated on the reactivity used the cement which alkali amount was varied from 0.7% to 2.0% as expressed by R2O. Test period was set up to 24 months, four times of the period of Standard Test. Although the expantion generally responded to the amount of alkali, the growth ratio of expantion from at 6 months to at 24 months evidently was low as shown Figure 5 except agressive aggregate D.

Effect of Suppressing Method on Reactive Aggregate

As shown Table 3, there obviously was no suppressing effect of the method of mixing the innocuous river sand to D aggregate, judged innocuous. The most effective suppressing method was to use the low-alkali cement especially fly ash or blast-furnace slag cement. Some reports regarding to this point have been published by the Committee of Japan Mining Industries Association (JMIA) as Nagataki (4) and Tamura (5).

DURABILITY INVESTIGATION OF THE EXPOSED FNS CONCRETE

Mixing Proportion of the Concrete

Materials and mix proportion of the test specimens are shown in Table 4. Using of FNS (A,B,C,D), six kinds of FNS concrete, and two kinds of natural sand concrete have been tested to investigate of the durability exposed at three district in Japan.

Compressive Strength

As shown Table 4, the durability of the exposed concrete, including natural sand concrete, was very satisfactory, evenly in the case of D aggregate with normal portland cement (R2O=0.78%).

TABLE 4 - Mix Proportion of Concrete for Exposure Test

Test No.	Kind of Sand FNS	Kind of Sand Sand	Cement Type	Cement R_2O	Sand Ratio %	Water	Cement	Aggregate FNS	Aggregate Sand	Aggregate Coarse
						Mix Proportion Kg/m3				
1	-	Sea	N	0.78	45.0	190	404	-	791	968
2	D	-	N	0.78	45.0	190	404	883	-	968
3	A	River	N	-	42.0	171	285	502	305	1067
4	A	-	N	0.67	39.5	160	285	837	-	1248
5	B	-	N	0.67	40.0	134	248	879	-	1304
6	C	-	N	0.67	38.0	160	286	823	-	1277
7	D	-	BB	0.57	40.0	148	264	853	-	1272
8	-	River	N	0.67	40.6	148	264	-	759	1258

TABLE 5 - Results of Exposure Test for FNS Concrete

Test No.	Compressive Strength MPa: Un-Exposed Concrete[I]	Compressive Strength MPa: Exposed Concrete[II]	[II]÷[I]	Modulus of Elasticity: Exposed Concrete MPa	Exposure Period: Days
1	34.1	52.3	1.53	309×10^3	3000
2	32.2	63.1	1.96	405×10^3	3000
3	30.6	32.1	1.05	320×10^3	3000
4	35.5	41.0	1.15	393×10^3	635
5	33.1	33.1	1.00	366×10^3	635
6	29.4	34.3	1.17	378×10^3	635
7	35.6	47.0	1.32	415×10^3	635
8	35.2	39.0	1.11	280×10^3	635

Modulus of elasticity in compression are tabulated in the Table 2.

Accelerated Test for Cored Concrete

For the purpose to estimate of potential reactivity of the exposed concrete, the accelerated test was made by the method which proposed by Public Works Resarch Institute, Ministry of Construction. The method of strage and measurement is the same for Martar Bar Method. As being indicated in Figure 7, the expantion of the cored concrete for three months test period were very small. The range of the expantion coefficient was from 0.005% to 0.009%, so we would judge that the reactivity of each aggregate used in the exposed concrete was apparently innocurous.

Neither gels nor cracks caused by expantion were observed on the surfaces of the cored specimens and of the exposed concrete structures.

CONCLUSIONS

In general we can make following statement:

1. Air cooled or air granulated slags from electric furnace are innocurous by Mortar Bar Method, while generally not innocurous by Chemical Method. Air cooled slags from rotary kiln also shows the same alkali reactivity.

2. The expantion of the mortar bars used innocurous slags are proportional to the Sc, not to the Rc.

3. The state of the all exposed concrete was very sound and neither gels nor cracks caused by expantion observed on the surfaces of the tested specimens.

ACKNOWLEDGEMENTS

This study is a part of work performed at a Committee of Japan Mining Industry Association, chaired by Professor S. Nagataki, Tokyo Institute of Technology. It is a pleasure to acknowledge the hospitality and encouragement of the members of the Committee. This work was sponsored and supported by Nippon Yakin Kogyo Co., Ltd., Pacific Metals Co., Ltd., and Sumitomo Metal Mining Co., Ltd., Members of JMIA. We also wish to thank the staff for their considerable assistance with the measurement.

SYMBOLS USED

FNS = Ferro-Nickel Slag

Rc = Decrease in Alkali Concentration mmol/l

Sc = Dissolved Amount of Silica mmol/l

R_2O = Na_2O Equivalent (Na_2O+0.658K_2O) alkali content of cement

N = Ordinary portland cement

NL = Ordinary portland cement (low alkali type)

FB = Portland fly ash cement Class B

BB = Portland blast furnace slag cement Class B

REFERENCES

1. Yamamoto, Y., Akiyama, A., 1986, Pro.7th I.C.A.R., Ottawa, 496.
2. Morinaga, K., et al, 1989, "A Study on Cooling Condition and Structure of Ferro Nickel Slag", Report, Committee
3. Katayama, T., 1991, "Petrografic Study of Potential Alkali-Reactivity of Ferro-Nickel Slag for Concrete Aggregates", Report, Committee, Ferro-Nickel Slag, J.M.I.A.
4. Nagataki, S., 1991 "Suppress Effect of Fly Ashes Against AAR Expantion of Ferro-Nickel Slags, Report, Committee, Ferro-Nickel Slag, JMIA.
5. Tamura, H., et al, 1991, "Concrete Bar and Accelerated Tests of Ferro-Nickel Slags", Report, Committee, Ferro-Nickel Slag, JMIA.
6. Hisaka, M., Yokoyama, M., 1990, "Suppress Effect of Low-Alkali Cement (NL, FB, BB)", Report, Reviewed, Committee, Ferro-Nickel Slag, JMIA.
7. Yokoyama, M., et al, 1990, "Effect of Long-Term and Hi-Alkali Cement on the Expantion of FNS Mortar Bars", Report, Reviewed, Committee, Ferro-Nickel Slag, JMIA.
8. Tomosawa, F., and Yokoyama, M., 1990, "Durability Tests of Ferro-Nickel Slag Concrete", Report, Reviewed, Committee, Ferro-Nickel Slag, JMIA.

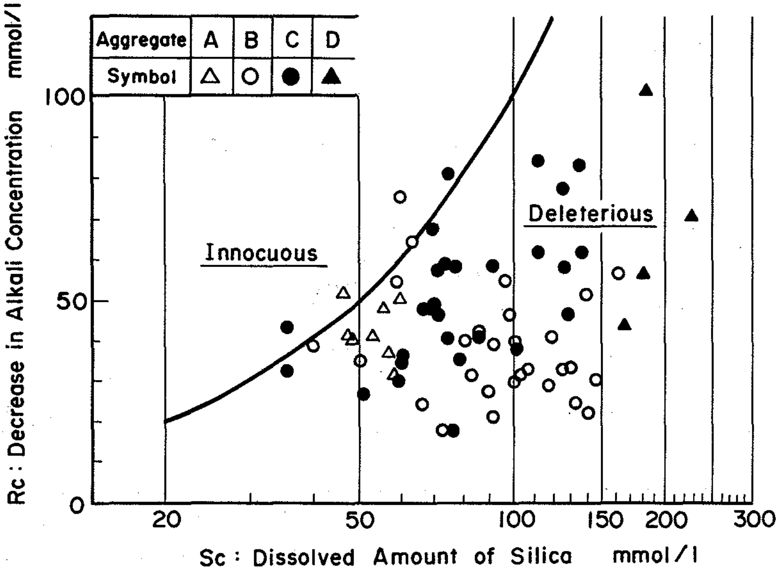


Figure 1 Test Results Sc and Rc from FNS Aggregates by Chemical Method

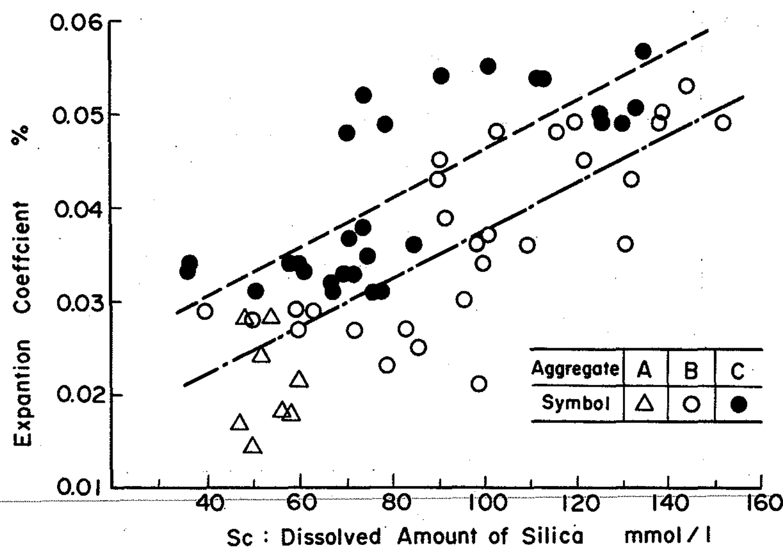


Figure 2 Relationship between Disolved Amount of Silica from FNS (A,B and C) and Expantion by Mortar Bar Method

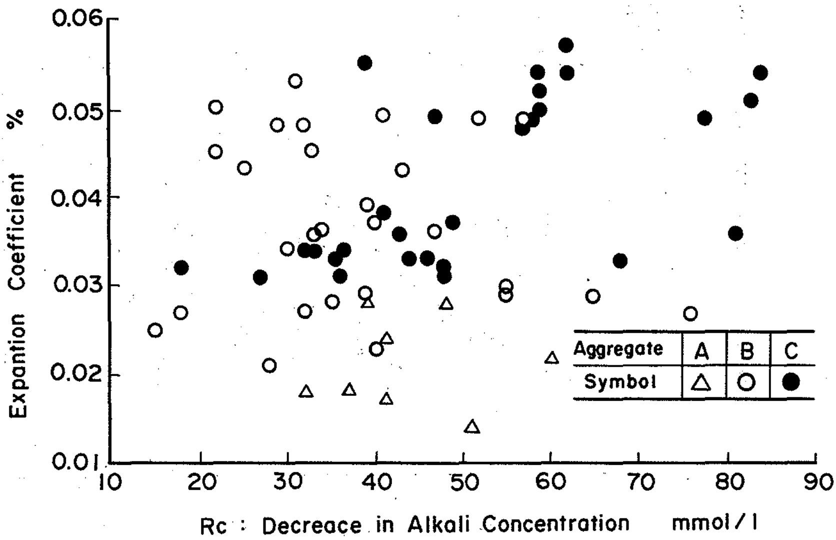


Figure 3 Relationship between Rc and Expantion by Mortar Bar Method

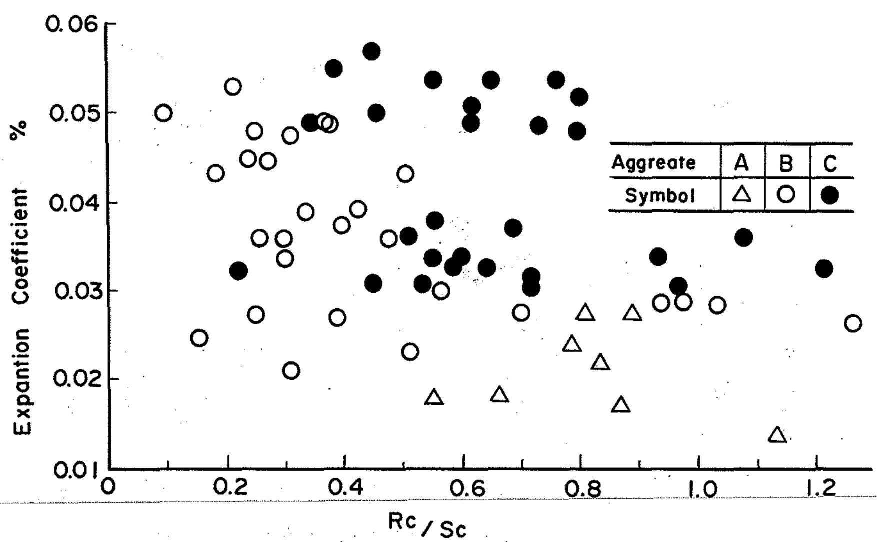


Figure 4 Relationship between Rc/Sc and Expantion by Mortar Bar Method

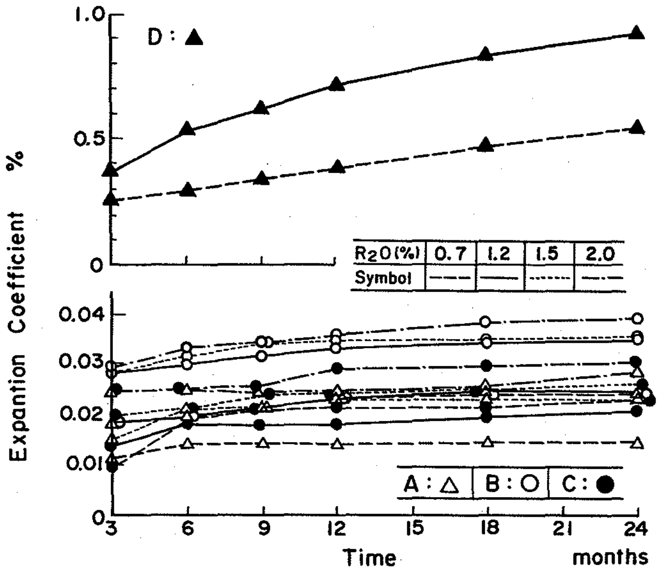
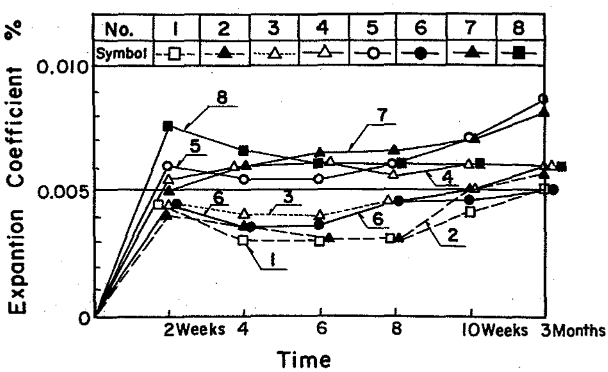


Figure 5 Effect of Alkali Content of Cement on Expantion for Long-Term Mortar Bar Test



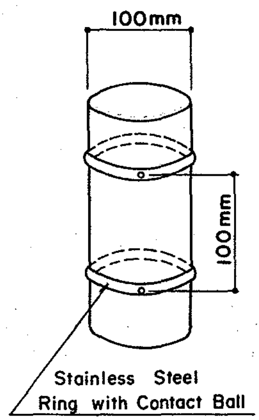


Figure 7 Accelerated Test Results of Cored Concrete from Exposed Test Specimens

Figure 6 Acceleration Test Specimen