

THE ALKALI-LEACHING PROPERTY OF SANDS AND INSPECTION ON ALKALI-LEACHING FROM AGGREGATE IN STRUCTURES

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Abstract

This paper reports on the alkali-leaching properties of sands using as an aggregate for concrete by the immersion test into a saturated calcium hydroxide solution. Samples were also taken from road structures to investigate their alkali content. Sands and cores drilled from structures to examine their lithological characteristics by means of polarization microscopy and EPMA color mapping for Na and K.

As a result, it was confirmed that alkali-leaching from aggregates in a saturated calcium hydroxide solution increased over time, and that the alkali-leaching properties of sands varied depending on the sand type. The alkali content of sand per gram of sand ranged from 0.1 to 0.4 mg/g, which nearly agreed with the sand-derived alkali content verified by testing on samples taken from structures. The mechanism of alkali-leaching from sand was also discussed based on the results of polarization microscopy and EPMA color mapping using polished thin sections.

Keywords: Sand, Alkali-leaching, Polarization microscopy, EPMA, Alkali-silica reaction

1 INTRODUCTION

Alkali-silica reaction (ASR) is a deterioration phenomenon that occurs when a silica mineral, alkali, and water coexist. A major source of alkali is cement, in which it is included in the form of sodium sulfate (Na_2SO_4) and potassium sulfate (K_2SO_4), which are derived from the feldspar, mica, and clay minerals in the clay materials of cement. Alkali-silica reaction in the Hokuriku District in Japan is characterized by its acceleration by sodium chloride (NaCl) supplied from outside as an air-borne salt or deicing salt deicers. Moreover, alkali-leaching from aggregates may also accelerate ASR from within concrete, as a number of rock types in this district are known to contain relatively high percentages of alkalis. Since alkali-leaching from aggregates is deemed proportional to its specific surface, the effect of fine aggregate is expected to be more significant than that of coarse aggregate [1]. Though ASR has been controlled basically in terms of the total alkali content of concrete (3 kg/m^3) in Japan, it may be necessary to review the current requirement in consideration of the effect of alkali-leaching from aggregates [2,3].

In this study, the authors investigated the lithological and mineralogical characteristics of representative river sands in the Hokuriku District, while comparing the alkali-leaching properties of river sands, land sands, beach sands, and crushed sands using as an aggregates for concrete in the Hokuriku and neighboring districts. A large number of concrete samples were also taken from road structures in Hokuriku to survey the current the alkali content of concrete, while dividing the alkali sources into cement and aggregate to examine the amount of alkali-leaching from sands. Polished thin sections were then prepared from specimens before and after alkali-leaching tests and cores drilled from road structures to examine their lithological characteristics by means of polarization microscopy and carry out EPMA color mapping analysis of Na and K. Based on these results, the authors proposed the appropriate total alkali content for concrete to inhibit ASR.

2 SANDS USED FOR TEST AND TEST METHODS

2.1 Sands under test

Sands used for alkali-leaching tests included total 26 fine sands (15 river sands, 3 beach sands, 2 land sands, and 6 crushed sands) from the Hokuriku district and neighbouring prefectures (N, T, I,

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and F), as well as parts of remoter prefectures (Na, S, and M) because of their distribution network. Table 1 gives the sources of the aggregates used for test.

For examining alkali-leaching in road structures, samples were taken from 23 bridge abutments, 4 bridge piers, and a box culvert of road structures in Fukui, Ishikawa, Toyama, and Niigata constructed between 1972 and 1985. Out of these 28 members, ASR-induced damage was observed in 22 members, while the other 6 members showed no damage due to ASR.

2.2 Rock compositions of sands

Approximately 5 g samples of river sands were embedded in epoxy to prepare two polished thin sections measuring 20 mm by 30 mm by 20 μm from each sample. The content of each rock type was calculated based on the area of each rock type on the polished sections determined by counting the points of 0.4 mm mesh through a polarization microscope. The average of two sections was taken as the rock composition of each river sands.

2.3 Mineral identification

After recognizing the rock types, sand samples were pounded in agate mortars to very fine powder samples of 90 μm sieve under. The powder samples were then subjected to X-ray diffraction (XRD, Cuk α -Ni filter, 40 kV-20 mA) to identify the component minerals in the rocks.

2.4 Alkali-leaching property tests on sand [4]

Twenty grams of sand (diameter 0.06-5.0mm) was added to a 40 ml saturated calcium hydroxide solution and agitated. The solution was then kept in a plastic container at 38 °C for a specified period and then subjected to atomic absorption photometry for Na⁺ and K⁺ concentrations in the solution. The amount of alkali-leaching (mg/g) was expressed as the equivalent alkali-leaching per gram of aggregate (mg/g, Na₂O + 0.658 K₂O).

2.5 Alkali-leaching property tests on aggregate

Water-soluble alkali content in concrete [5]

Concrete samples were ground to less than 100 μm in diameter for the content of water-soluble alkali (Na₂O + 0.658 K₂O). Ten grams of samples were added to distilled water at 40 °C, and the solution was agitated for 30 min. to measure the alkali concentration (Na⁺, K⁺) of the filtrate by atomic absorption photometry in terms of the equivalent alkali content (Na₂O + 0.658 K₂O).

Minimum alkali content of cement by EPMA

Cores were drilled from road structures built 20 or more years ago by the method proposed by Katayama et al. [6] and sliced to prepare polished thin sections 20 μm in thickness for identifying unhydrated cement particles by polarization microscopy. After depositing carbon vapor on the samples, the minimum alkali content of cement was determined by quantitative analysis for each of the alite (C₃S), belite (β C₂S), aluminate (C₃A), and ferrite (C₄AF) phases. The alkali content was calculated by assuming the mass proportions of C₃S, β C₂S, C₃A, and C₄ AF to be 0.6:0.2:0.1:0.1 after converting to an equivalent alkali content (Na₂O + 0.658 K₂O). Note that the alkali content of cement does not include water-soluble alkalis, such as alkali sulfates (NaSO₄, K₂SO₄), which are dissolved in water immediately after coming into contact with water.

2.6 Confirmation of alkali distribution by EPMA

Polished thin sections 20 μm in thickness were prepared from cores drilled from road structures and river sand samples embedded in low viscosity epoxy before and after alkali-leaching tests. The rock types in these thin sections were identified by polarization microscopy. The samples were then coated with vapor carbon and subjected to mapping for Na and K in specific rock types using EPMA.

3 CHARACTERISTICS OF RIVER SANDS

3.1 Rock type classification

In contrast to homogeneous crushed sand, river sand consists of a wide variety of rocks. Figure 1 shows the rock compositions of eight types of river sands. These sands are characterized by the inclusion of rock-forming minerals in addition to rocks themselves. The proportions of volcanic rocks (andesite, rhyolite, tuff) and sedimental rocks (chert), which have been proven relative to ASR deterioration, widely varied from one river to another. Also, structures made using aggregates from

five of the eight river excepting rivers T in N prefecture, river N in Na prefecture, and river Ch in Na prefecture actually showed ASR-induced damage.

3.2 Mineral composition

Several rock types were selected from river sands shown in Figure 1 and subjected to powder X-ray diffraction. Table 2 gives the results of powder X-ray diffraction together with those of river gravel for comparison. Note that the results of mineral identification were divided into three levels by comparison of the numbers of relative peaks in the X-ray diffraction of rock types. Quartz is more contained in river sands than feldspar, whereas feldspar is more contained in river gravels than quartz. This suggests that the alkali content of river gravel is higher than that of river sand. Though the surface area of river gravel is smaller than that of river sand, it was inferred that a greater amount of alkali can leach out if ASR causes cracking in river gravel.

4 ALKALI-LEACHING PROPERTIES OF SANDS

Figure 2 shows the alkali-leaching properties of sands. Depending on the rock compositions of the sands, their sodium- and potassium-leaching properties can be classified into two patterns: one levelling off by a test period of 91 days and the other continuing to increase thereafter. Also, the leaching behaviour of sodium widely differed from that of potassium. Whereas potassium began to leach out at an early time, the leaching of sodium was slow in the beginning, progressively increasing over time. The alkali-leaching amounts of sands from rivers in N and I prefectures mostly levelled off by an immersion period of 91 days, whereas those of sands from rivers in T and Na prefectures continued to increase after 91 days. Relatively large amounts of alkali-leaching were observed from beach sands than from land sands. Crushed sandstone and crushed granite from S and M prefectures also showed relatively large amounts of alkali-leaching. Whereas no alkali-leaching was observed from crushed limestone from O area, N prefecture, a certain amount of alkali-leaching was found from crushed limestone from O area, S prefecture, presumably due to the difference in the amounts of impurities in limestone.

At the end of an immersion period of 6 months, the alkali-leaching amounts from river sands ranged from 0.1 to 0.4 mg/g. The maximum value recorded by sand from S river, T prefecture, amounted to 0.4 mg/g, which corresponded to an equivalent alkali content of 0.32 kg/m³ in normally proportioned concrete with a fine aggregate content of 800 kg/m³. In consideration of the large amount for 6 months and the fact that alkali-leaching from some sands does not level off in this period, it is deemed appropriate to assume a maximum alkali-leaching from river sand to be around 0.5 kg/m³. This is as high as 20% of the requirement for the total alkali content of cement (2.5 kg/m³). It is therefore necessary to include the effect of alkali-leaching from aggregates along with the effect of alkali derived from NaCl contained in sea sand and sea gravel. Accordingly, it is judged reasonable to apply the requirement by temporarily setting the limit at 2 kg/m³ for cement alone and 2.5 kg/m³ for cement plus other admixtures to incorporate the effect of alkali-leaching from aggregate.

5 ALKALI-LEACHING IN PROPERTIES STRUCTURES

5.1 Minimum alkali content of cement by EPMA

Unhydrated cement particles were detected using reflected images of polished thin sections made from cores drilled from structures to conduct quantitative analysis by EPMA. Note that the cement used in the structures was all normal portland cement. Figure 3 shows the analysis results together with the time-related changes in the average alkali content of cement. The alkali content values do not include the water-soluble alkalis that dissolve in water immediately after coming into contact with water, such as alkali sulfates. Though the alkali content of cement is generally examined by wet analysis, these results by EPMA are found to agree with the data, with no marked scatter by time or manufacturer, proving to be adequate analysis results.

5.2 Classification of alkali sources and calculation procedure [6]

Table 3 gives the analysis and estimation results of water-soluble alkali content (Na₂O + 0.658 K₂O) in concrete. The densities of concrete and cement were calculated from the specified mixture proportions of concrete. The estimations are based on the following assumptions:

- (1) Average analysis values given by the cement manufacturers (0.93%, 0.68%, 0.51%, and 0.79% for cements by M, D, O, and S companies, respectively) were adopted as the minimum alkali content of cement by EPMA.
- (2) The content of water-soluble alkalis, such as alkali sulfates, which was assumed to be 20% of

- the minimum alkali content by EPMA, was added to be included in the total alkali content of cement.
- (3) The water-soluble alkali content of aggregate was assumed to be the water-soluble alkali content of concrete subtracted by the water-soluble alkali content of cement.
 - (4) The water-soluble alkali content derived from sand was assumed to correspond to 50% of the mass percentage of sand (sand-to-total aggregate ratio \times 50%), as the feldspar content of river sand is lower than that of river gravel.

Note that alkalis from chemical admixtures were assumed to be negligible in this study. Based on these assumptions, the water-soluble alkali content derived from sand was estimated to be 0.2 kg/m³ on average (0.1 to 0.7 kg/m³). This corresponds to an alkali content of 0.3 mg per gram of sand on average (0.1 mg/g to 0.9 mg/g), nearly agreeing with the alkali-leaching test results of sand.

Structures tended to show no ASR events when the average total alkali content of cement plus average water-soluble alkali content of sand was not more than 2.5 kg/m³, whereas they showed ASR events when it exceeded 3 kg/m³. This ascertained the necessity for applying the requirement for the total alkali content by setting the limits at 2 kg/m³ for cement alone and 2.5 kg/m³ for cement plus other admixtures as stated in the previous section.

6 COLOR MAPPING OF SANDS BY EPMA

Figures 4 to 6 show the results of polarization microscopy. Volcanic rocks and tuff that display black color under perpendicular Nicol prisms were inferred to be volcanic glass. Volcanic glass tended to fill spaces between other minerals, which was relatively small in amount. Also, those partially display yellow to brown were inferred to be altered feldspar. Weathering, alteration, and erosion of volcanic glass are therefore found more significant on sand particles.

Figure 7 shows the results of sand color mapping by EPMA before alkali-leaching tests. No marked effect of sand interfaces was observed, with the concentrations of sodium and potassium both in the phenocrysts and groundmass being constant. Further more, the alkali concentration tended to be high in areas that were inferred to be altered feldspar. On the other hand, the alkali concentration of the areas that were inferred to be altered feldspar tended to be low in the results of sand color mapping by EPMA after alkali-leaching testing shown in Figure 8 and the results of EPMA mapping of core samples drilled from structures shown in Figure 9. The alkali concentration on the sand particle surfaces was also found lower than within the particles. It was therefore inferred that sodium and potassium leached out from the surfaces of sand particles. Since feldspars are originally rich in alkalis (Na and K), the sodium concentration in sand particles was considered to decrease, while the sodium concentration in the pore solutions in concrete increased accordingly.

Alkali-leaching from sand particles immersed in a calcium hydroxide solution shown in Figure 2 reveals that potassium leaches earlier than sodium, tending to level off after an immersion period of 28 days. This represents early potassium leaching from volcanic glass. The amount of such leaching from volcanic glass was limited, presumably because the volcanic glass content was low when compared with other minerals as found in the results of polarization microscopy shown in Figures 4 to 6. On the other hand, sodium either leveled off by an immersion period of 91 days or continued to increase (see Figure 2). Based on Figure 8 and Figure 9, it was inferred that sodium that leaches out at an early stage was derived from altered feldspar on the surfaces of sand particles. Alkalies within feldspar then began to leach out as the Ca(OH)₂ solution seeped into sand particles. Judging from the fact that sodium leaching did not level off at the end of a 182 day period of alkali-leaching tests and that a relatively large amount of sodium remained within sand particles by EPMA color mapping (see Figure 8 and Figure 9), sodium tended to continue leaching for a long time, aggravating ASR for a long time.

7 CONCLUSIONS

In this study, alkali-leaching properties of river sands, land sands, beach sands, and crushed sands from the Hokuriku District and nearby areas were examined. The alkali sources of road structures were also divided into cement and aggregate to verify the validity of alkali-leaching test. The results of polarization microscopy were combined with the results of EPMA color mapping to investigate alkali-leaching from aggregate.

Major results of this study are summarized as follows:

- (1) River sands contained alkali-silica reactive volcanic rocks (andesite, rhyolite, and tuff), with their proportions widely varying from one river to another.
- (2) The major mineral contained in river sands was quartz, their feldspar content tending to be lower than in river gravel. Also, altered feldspar was observed by polarization microscopy in

- igneous river sands within concrete.
- (3) The sodium and potassium leaching properties of river sands varied depending on the proportions of rocks and rock forming minerals. Whereas sodium continued to leach out into a calcium hydroxide solution for a long time, the leaching of potassium tended to level off at an early stage. The sodium-leaching properties of sand were therefore considered to strongly affect its amount of alkali-leaching.
 - (4) The amount of alkali-leaching from sand corresponded to 0.5 kg per unit volume of concrete at the maximum. In consideration of this alkali content from sand, it was deemed appropriate in the Hokuriku District to apply a requirement for a total alkali content of 2 kg/m³ for cement alone and 2.5 kg/m³ for concrete.
 - (5) EPMA analysis of polished thin sections revealed that the alkali concentrations (Na, K) in areas of altered feldspar were relatively low, showing an evidence of alkali-leaching. Early leaching of potassium was derived from volcanic glass, which was followed by long-term leaching of sodium as the calcium hydroxide solution seeped into specimens.

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TABLE 1 : Sands used for test.

Prefecture	River system or zone	Compositions of sands
N.Pre	Sa.Riv	River sand
	Ar.Riv	River sand
	T.Riv	River sand
	Ag.Riv	River sand
	Si.Riv	River sand
	U.Riv	River sand
	M.Riv	Beach sand
	O.Zone	Crushed limestone
Na.Pre	N.Riv	River sand
	Ch.Riv	River sand
T.Pre	H.Riv	River sand
	J.Riv	River sand
	G.Riv	River sand
	S.Riv	River sand
I.Pre	T.Riv	River sand
	U.Zone	Beach sand
	O.Zone	Beach sand
F.Pre	Q.Riv	River sand
	H.Zone	Crusyued hard sandstone
S.Pre	A.Riv	River sand
	N.Zone	Land sand
	K.Zone	Land sand
	H.Zone	Crushed hard limestone
	O.Zone	Crushed chert
	R.Zone	Crushed sandstone/granite
M.Pre	I.Zone	Crusyued hard sandstone

TABLE 2 : Types of reactive components identified by XRD.

Variety of aggregates	River system	Aggregates content	Mineral compositions							
			Feldspar	Quartz	Cristobalite	Tridymite	Mica	Chlorite	Amphibole	Pyroxene
River sands	N.Pre-Ag.Riv	Rhyolite	◎	◎				△	△	
	N.Pre-T.Riv	Mudstone	○	◎			○	△		
	N.Pre-Ch.Riv	Rhyolite	○	◎				△		
	N.Pre-N.Riv	Andesite	○	△		△		△	△	△
	T.Pre-S.Riv	Rhyolite	○	◎			△			
	T.Pre-G.Riv	Rhyolite	○	◎			○			
	T.Pre-H.Riv	Granite	◎	◎			○		△	
	F.Pre-Q.Riv	Rhyolite	○	◎			△	△		
River gravels	N.Pre-Ag.Riv	Tuff	◎	◎						
		Rhyolite	△	◎						
	N.Pre-Si.Riv	Andesite	◎	△						○
	N.Pre-T.Riv	Chert	△	◎			△	△		
	N.Pre-Ch.Riv	Rhyolitic welded tuff	○	◎				△		
	N.Pre-N.Riv	Rhyolitic welded tuff	○	◎						
	T.Pre-H.Riv	Rhyolite	○	◎			△	○	△	
		Rhyolitic welded tuff	○	◎						
	T.Pre-G.Riv	Andesite	○	△	○					
		Andesite	○	△	○					△
	T.Pre-S.Riv	Daite	○	◎						
		Rhyolitic welded tuff	○	◎						
	I.Pre-T.Riv	Daitic welded tuff	○	◎				△		
	F.Pre-Q.Riv	Rhyolitic tuff	○	◎			△			
		Andesite	○		◎					

◎:Dominant, ○:Abundant, △:Common

TABLE 3 : Estimation of alkalis from sands in concrete.

Pref.	Structure	ASR occur or occur	Const- ruction	Cement brand	Concrete						Cement			Aggregate	Sand		
					(kg/m³)	(kg/m³)	(%)	②Cement soluble Na₂Oeq.	③EPMA Na₂Oeq.	④Apparent Na₂Oeq.	⑤Water- soluble Na₂Oeq	⑥Water- soluble Na₂Oeq	⑦s/a	⑧Water- soluble Na₂Oeq	Water- soluble Na₂Oeq		
F.Pre.	F1Br-Abut	Occur	1975	M	3.97	290	(0.93)	3.2	1.6	2.4	36.6	0.4	0.6				
T.Pre.	T1Br-Pier	Occur	1973	D	1.47	290	0.68	2.4	1.2	0.3	38.5	0.1	0.1				
T.Pre.	T2Va-Abut	Occur	1973	S	4.15	290	0.84	2.9	1.5	2.7	40.4	0.5	0.7				
T.Pre.	T3Br-Pier	Occur	1973	S	2.13	290	(0.79)	2.7	1.4	0.8	38.2	0.1	0.2				
T.Pre.	T4Br-Abut	Occur	1975	S	2.59	290	(0.79)	2.7	1.4	1.2	36.8	0.2	0.3				
T.Pre.	T5Va-Abut	Occur	1975	S	2.74	290	(0.79)	2.7	1.4	1.4	36.8	0.3	0.4				
T.Pre.	T6Br-Abut	Occur	1975	S	2.61	290	(0.79)	2.7	1.4	1.2	36.8	0.2	0.3				
T.Pre.	T7Va-Abut	Occur	1975	S	2.89	290	(0.79)	2.7	1.4	1.5	36.8	0.3	0.4				
T.Pre.	T8Va-Abut	Occur	1975	M	3.05	290	(0.93)	3.2	1.6	1.4	36.6	0.3	0.4				
T.Pre.	T9Br-Abut	Occur	1975	M	1.88	290	0.74	2.6	1.3	0.6	38.8	0.1	0.2				
T.Pre.	T10Br-Abut	Occur	1975	M	3.05	290	(0.93)	3.2	1.6	1.4	36.6	0.3	0.4				
T.Pre.	T10Br-Pier	Occur	1975	M	3.09	290	(0.93)	3.2	1.6	1.5	36.6	0.3	0.4				
T.Pre.	T10Br-Abut	Occur	1975	M	3.09	290	1.04	3.6	1.8	1.3	36.6	0.2	0.3				
T.Pre.	T11Br-Abut	Not occur	1980	O	1.72	290	0.50	1.7	0.9	0.9	39.3	0.2	0.2				
T.Pre.	T12Br-Abut	Occur	1980	S	3.09	300	(0.79)	2.8	1.4	1.7	40.7	0.3	0.4				
T.Pre.	T13Va-Abut	Occur	1980	D	2.34	300	0.74	2.7	1.3	1.0	41.4	0.2	0.3				
T.Pre.	T13Va-Pier	Occur	1980	D	2.35	300	(0.68)	2.4	1.2	1.1	41.4	0.2	0.3				
T.Pre.	T14Br-Abut	Occur	1983	M	2.61	280	1.01	3.4	1.7	0.9	39.5	0.2	0.2				
T.Pre.	T15Br-Abut	Occur	1983	A	2.99	280	0.77	2.6	1.3	1.7	39.5	0.3	0.4				
T.Pre.	T16Va-Abut	Not occur	1983	M	2.77	280	1.01	3.4	1.7	1.1	39.5	0.2	0.3				
T.Pre.	T17Va-Abut	Not occur	1983	S	2.63	280	0.74	2.5	1.2	1.4	40.6	0.3	0.4				
T.Pre.	T18Br-Abut	Not occur	1983	D	1.94	290	(0.68)	2.4	1.2	0.8	37.6	0.1	0.2				
T.Pre.	T19Br-Abut	Not occur	1983	O	1.47	280	(0.51)	1.7	0.9	0.6	38.6	0.1	0.2				
T.Pre.	T20Va-Abut	Occur	1983	D	2.50	280	(0.68)	2.3	1.1	1.4	41.7	0.3	0.4				
N.Pre.	N1Va-Pier	Occur	1985	D	4.38	300	0.61	2.2	1.1	3.3	42.4	0.7	0.9				
N.Pre.	N2Va-Abut	Not occur	1980	D	1.76	290	(0.68)	2.4	1.2	0.6	38.3	0.1	0.1				
N.Pre.	N3Br-Abut	Occur	1978	S	2.20	290	0.66	2.3	1.1	1.0	33.0	0.2	0.3				
N.Pre.	N4Va-Abut	Occur	1978	O	2.08	290	0.52	1.8	0.9	1.2	37.5	0.2	0.3				
N.Pre.	N5Br-Abut	Occur	1978	D	2.48	290	(0.68)	2.4	1.2	1.3	37.2	0.2	0.3				
All average					2.62						2.7	1.3	1.3	0.2			
ASR not occur average					2.05						2.3	1.2	0.9	0.2			
ASR occur average					2.77						2.7	1.4	1.4	0.3			
() Average analysis values given by the cement manufacturers																	

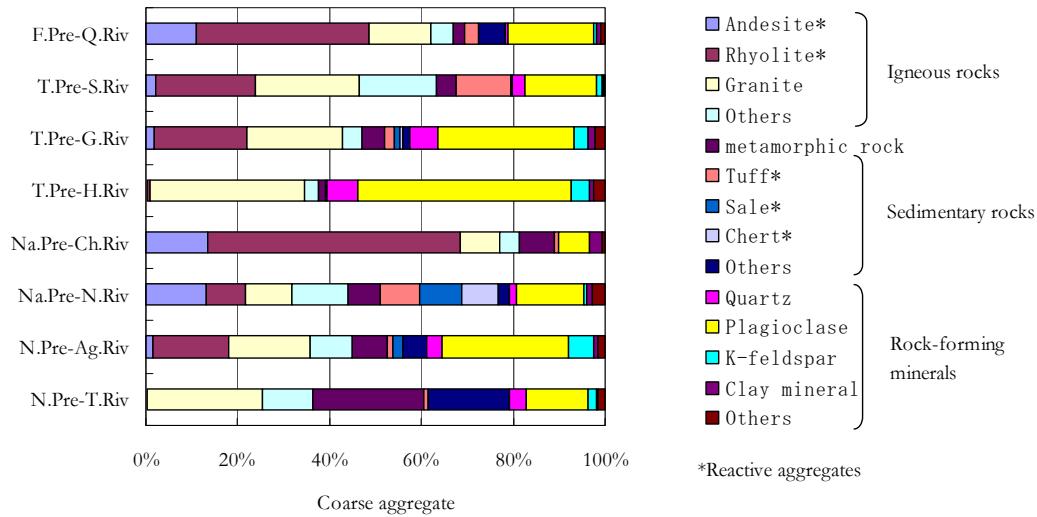


Figure 1 : Content of reactive rocks in river sands.

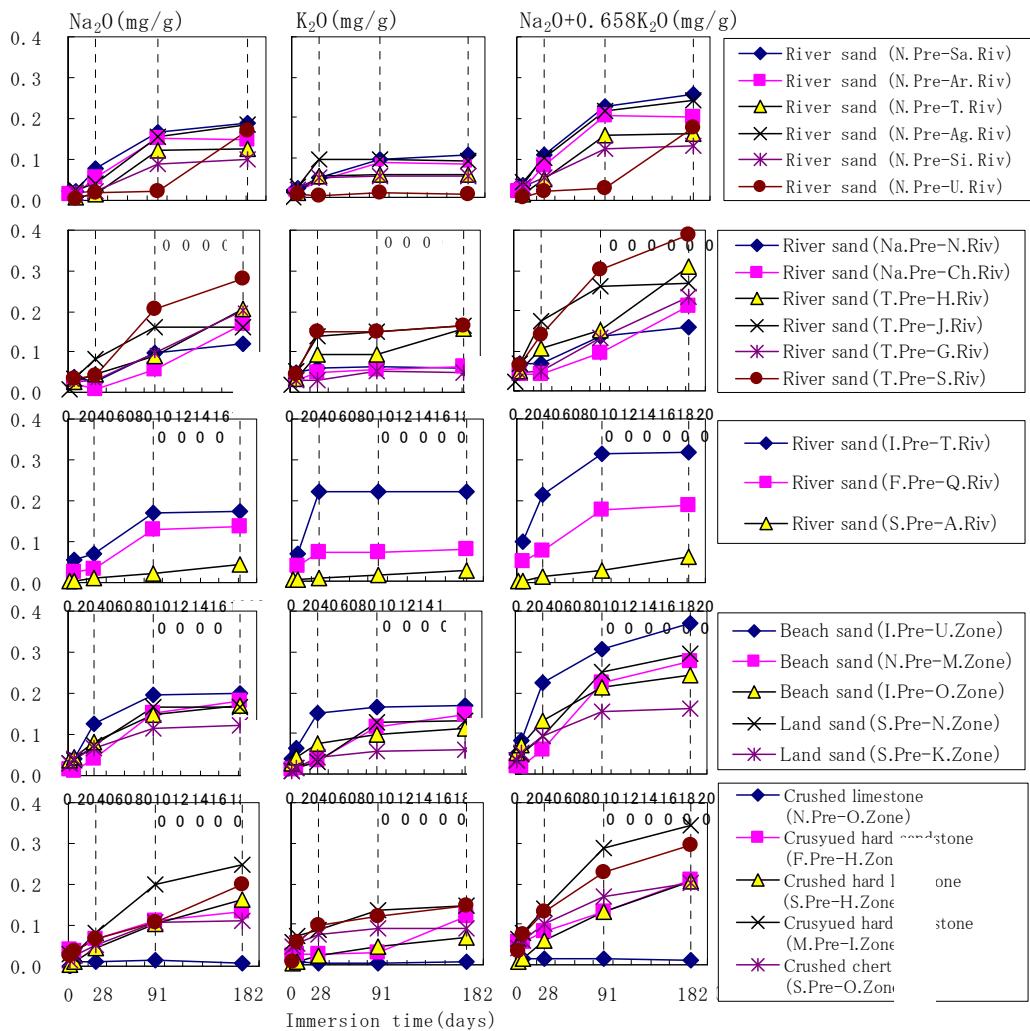


Figure 2 : Amount of alkalis leached from sands in immersion test.

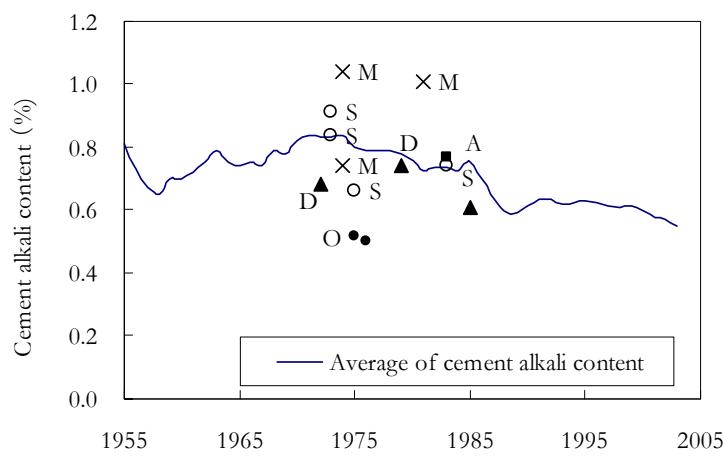


Figure 3 Estimated minimum alkali content of original cement by EPMA.

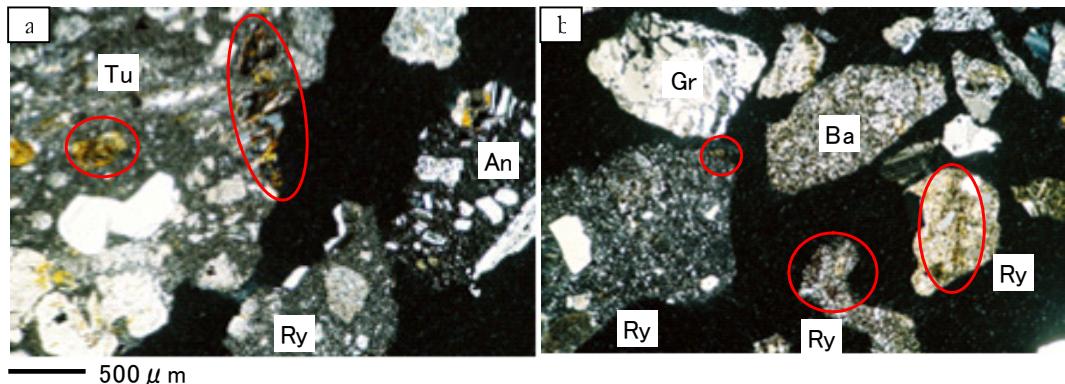


Figure 4 Sands by polarization microscopy photographs under perpendicular Nicol prisms before alkali-leaching property test, a : F.Pre-Q.Riv, b : T.Pre-S.Riv, Ba : Basalt, Ry : Rhyolite, An : Andesite, Tu : tuff, Gr : Granite, ○ : Altered feldspar.

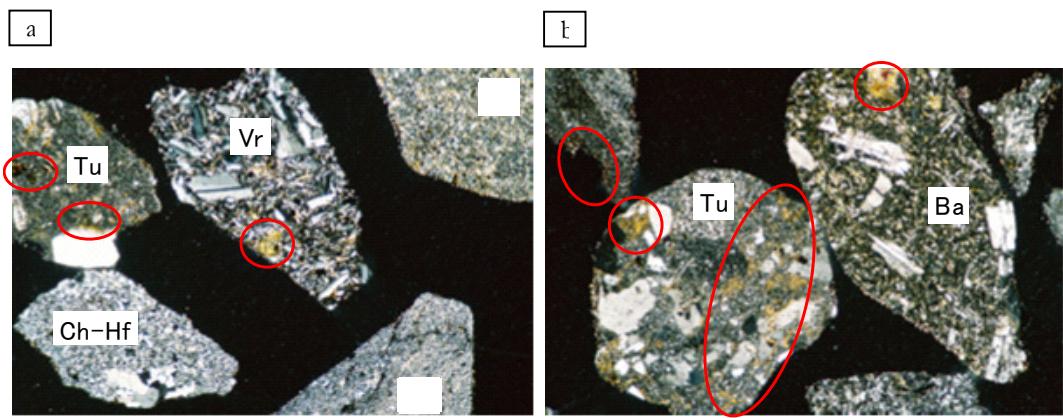


Figure 5 : Sands polarization microscopy photographs under perpendicular Nicol prisms after alkali-leaching property test, a : F.Pre-Q.Riv, b : T.Pre-S.Riv, Vr : Volcanic rock, Ba : Basalt, Tu : Tuff, Ch-Hf : Chert-hornfence, M : Mudstone, ○ : Altered feldspar.

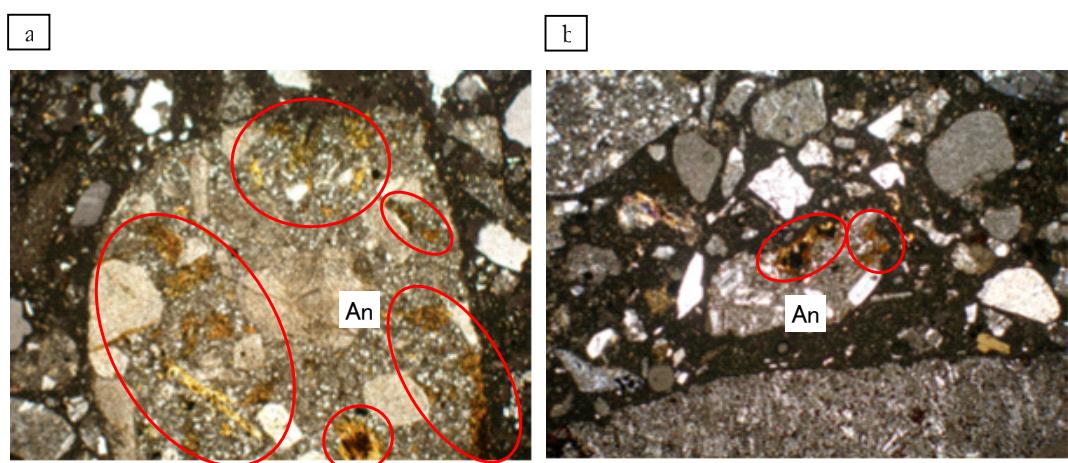


Figure 6 : Andesites in concrete structure by polarization microscopy photographs under perpendicular Nicol prisms, a : T.Pre-O.Riv, b : N.Pre-H.Riv, An : Andesite, ○ : Altered feldspar.

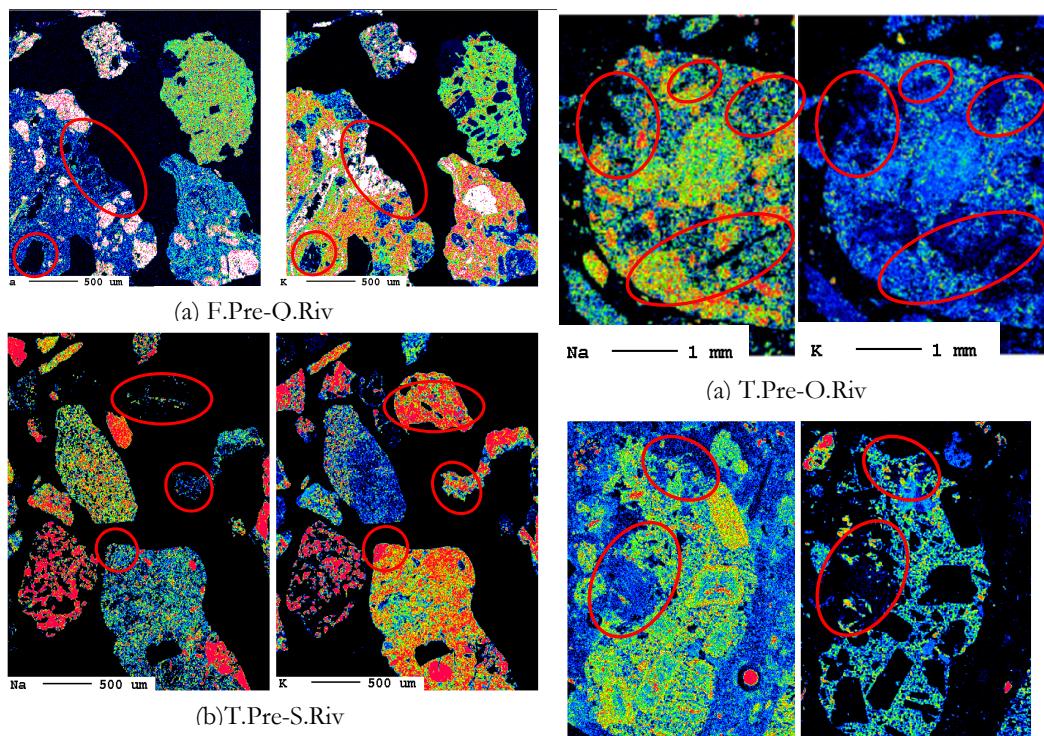


Figure 7 : Sands color mapping by EPMA before alkali-leaching testing.

Low ← Concentration → High
○ : Altered feldspar

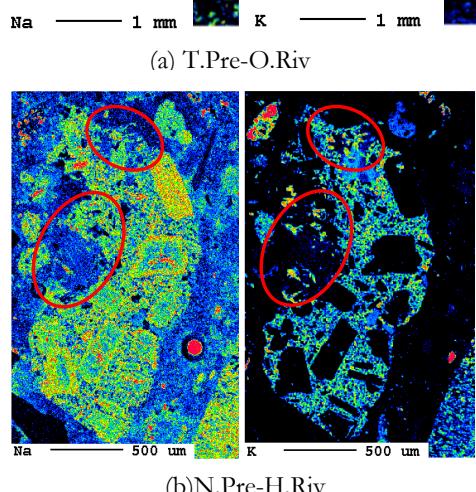


Figure 9 : Sands color mapping of core samples drilled from road structures.

Low ← Concentration → High
○ : Altered feldspar

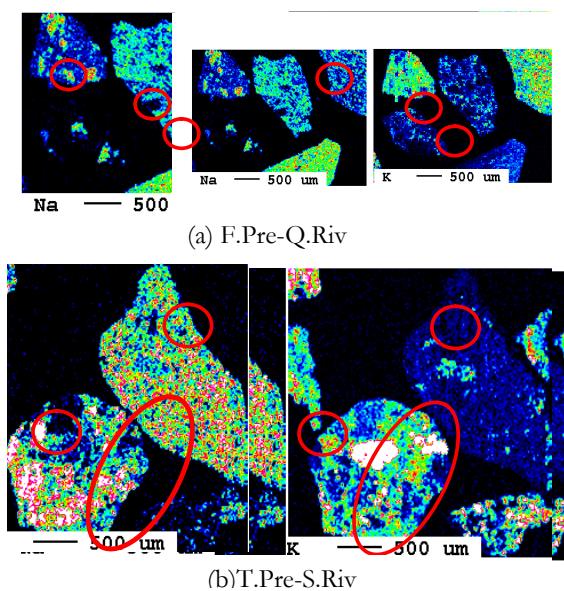


Figure 8 : Sands color mapping by EPMA before alkali-leaching testing.

Low ← Concentration → High
○ : Altered feldspar