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Characterization of Leaching Behavior of Recycled Concrete Used for Scour Prevention

Characterization of Leaching Behavior of Recycled Concrete Used for Scour Prevention

Juhyung LEE*, Kiseok KWAK*, Jaehyeon PARK* and Moonkyung CHUNG**

* Korea Institute of Construction Technology/Geotechnical Engineering Research Department, Koyang, Korea

** Korea Institute of Construction Technology/International Cooperation & Public Information Division, Koyang, Korea

A series of leaching test was conducted to assess the potential environmental risk of recycled concrete produced in Korea when it is utilized as a material for protecting bridge piers against scour. Recycled concrete can be used economically to fill the scour hole directly, as granular filters of riprap or as filling materials of gabions, geocontainers, stone mattresses and so on when natural material is not enough. These applications using recycled concrete are especially effective in the side of resources saving and environmental preservation. In this study, several methods were included such as continuous batch test(DIN 38414-S4), availability leaching test(NEN 7341), pH-stat test(CEN/TC 292/WG6) and tank diffusion test(NEN 7345). On all of the tests, nearly all the trace elements were found to be low in their concentrations while some elements were recorded under detection limits. There are no criteria for environmental risk in methods we used in this study. However, conditions such as contact time, pH and so on were much more rigorous than other commonly adapted method including TCLP and domestic testing method for solid waste, the trace elemental concentrations are under the criteria for hazardous material set by the TCLP and domestic method. Based on the test results, it may be concluded that the use of recycled concrete as a scour countermeasure would be an acceptable practice as far as trace elements are concerned.

I. Introduction

The construction and demolition waste is the necessary consequences occurred during the redevelopment and reconstruction and it shows the rapidly increased amount, among which waste concrete accounts for about 67%. Advanced countries such as Japan and US have made every effort to recycle the waste concrete and especially, concentrated their effort on the development of advanced utilization technology to utilize the recycled aggregates obtained from demolition of waste concrete and other procedures as highly value-added materials such as road repairing material, compound for concrete and raw material of cement as well as simple process such as reclamation. At present, the country has tried to utilize the construction and demolition waste highly and the recycled aggregates are gradually utilized and commercialized as road base material, road sub-base material and recycled concrete block.

Before utilizing the recycled aggregates, it is important to clearly characterize the recycled aggregates environmentally and technologically and to secure the safety. Especially, the recycled aggregates containing cement may produce heavy metals and harmful mineral ions when contacting with water, probably resulting in environmental risk. This study was intended to evaluate the environmental risk of the recycled aggregates with leaching test as the basic research to utilize the recycled aggregates as the scour-protective aggregate of bridges. Recycled concrete can be used economically to fill the scour hole directly, as granular filters of riprap or as filling materials of gabions, geocontainers, stone mattresses and so on when natural material is not enough. These applications using recycled concrete are especially effective in the side of resources saving and environmental preservation.

Especially, this study deals with the environmental assessment to the recycled aggregates used as a scour-protective aggregate, which is to contact water for a long time daily over several tens of years, so the prerequisite research is to analyze the leaching characteristics of elements quantitatively and qualitatively. Solid Waste Process Test and TCLP test most used when assessing the leaching characteristics of solid waste may advantageously assess the short-term effects qualitatively as relatively simple tests costing reasonably but both tests have limitations to assess the long-term and comprehensive risk in accordance with physically and chemically environmental changes. To overcome the shortcomings, this study is to draw out a more qualitative model applicable to fields by adopting various leaching methods to simulate leaching reactions in various environments. The purposes of this study is to 1) determine whether leaching degree of a certain material complies with the environmental standards through various proven leaching tests and 2) assess the potential effects to the environment quantitatively by verifying the leaching characteristics under various physical and chemical conditions when the recycled aggregate contacts water.

II. Test Methods

1. Test Materials

The recycled aggregates are categorized into two types; type 1 recycled aggregate and type 2 recycled aggregate and this study chose the type 2 recycled aggregate, which is easy to process and economical, to research. Table 1 shows the general physical properties of type 1 & 2 recycled aggregate and natural aggregate. As seen in the table, it is found that there is no significantly physical difference between type 1 recycled aggregate and natural

TABLE 1.
PHYSICAL PROPERTIES OF RECYCLED AGGREGATES AND NATURAL AGGREGATE

Property	type 1 recycled aggregate	type 2 recycled aggregate	natural aggregate
Unit weight(kg/m^3)	1,579	1,406	1,509
Specific gravity(g/cm^3)	2.61	2.43	2.64
Water absorption(%)	1.14	3.12	1.13
Unit cost($/m^3)	6	3	18

aggregate and that type 2 recycled aggregate is very economical. The type 2 recycled aggregate used as test materials was offered by a waste concrete recycling company in Korea, and it shows 30~70mm of grade and 35~52% of abrasion loss.

2. *Leaching Test*

The conditions when utilizing the recycled aggregate as a scour-protective aggregate are 1) that it continues to contact water and, 2) that it flows, not a lake without stream, so leached materials are diluted and spread over, instead of sedimentation. Therefore, the maximum leaching possibility of elements was calculated by executing availability leaching test. At the moment, to apply worse condition when assessing the leaching possibility of element, the recycled aggregates have been crushed smaller than 125μm. That's why smaller particles may facilitate more leaching because of increased surface area. In addition to availability leaching test with the crushed samples, the serial batch test has been also performed with the raw(not crushed) samples.

In addition, considering that river water does not have uniform pH at positions and that pH might be changed due to acid rain or changes in the neighboring environment, pH-stat test has been performed to examine the changes in leaching characteristics depending on pH. Unlike the availability leaching test in which particle size has been adjusted, the leaching degree of elements has been calculated in other conditions by using serial batch test without any adjustment of particles.

With the above test, it is reasonably determined that the diffusion of leaching of the recycled aggregate would depend on a function of the surface area. Therefore, to examine the leaching characteristics due to the surface diffusion when it continues to contact water for a long time, the accumulative leaching characteristics of elements has been examined by using a tank test. It is available as long as the particle diameter is 40mm and larger.

A. *Serial batch leaching test - modified after DIN 38414-S4*

The serial batch leaching test is a test leaching elements continuously simply by exchanging a solution without a sample to leach exchanged, with which the reaction time of the batch test may be extended. After adding 200g of the raw(not crushed) sample and 600mL(LS ratio 3:1) of distilled water to a 1000mL polyethylene bottle, the mixture has been agitated at a speed of 30rpm/h by a rolling mixer for 24 hours. Once the first 24 hours agitation is finished, the solution is removed by 0.45μm filter and then, the bottle is filled with distilled water and agitated for 24 hours. The procedure is repeated for four times. The recycled aggregate samples used in the serial batch leaching test was performed by dividing into cleaned one and not cleaned one. That is, the cleaning procedure is to clean it with flowing water for a minute as it is normally cleaned in the fields while the other one(not cleaned) is not processed with the above process.

B. *Availability leaching test - Dutch availability leaching test NEN 7341*

It consists of processes to crush the recycled aggregate smaller than 125μm, mix 8g of the crushed aggregate and 800ml distilled water in a 1,000mL beaker and agitate them with a magnetic bar. At the moment, for the first four hours, the pH is adjusted to 7, the solution is removed in 4 hours, it is filled with distilled water again and then, it is agitated for 18 hours with pH set to 4. After mixing a sample of pH4 and a sample of pH7 and filtrating the mixture with a 0.45μm filter, it is readily analyzed. For the adjustment of pH, a peristaltic pump and a controller were used and 0.1M diluted nitric acid was used to adjust pH because the recycled aggregate itself is 11~13, which is strong alkali.

C. *pH-stat leaching test - CEN/TC 292/WG6, EU standard method of pH dependence test*

For the test, 30g of the recycled aggregate crushed smaller than 125μm and 300mL of distilled water were mixed into a 500mL beaker(LS ratio 10:1) and its pH is adjusted at 9 steps of 4, 5, 5.5, 7, 8, 9, 10, 11 and 12 by using a magnetic bar(Fig. 1). Then, it was agitated for each pH level for 24 hours. For pH adjustment, 0.1M diluted nitric acid and 0.1M diluted sodium hydroxide were used, in which pH has been uniformly maintained with a peristaltic pump and a controller.

D. *Tank diffusion test - NEN7345, Dutch diffusion leaching test*

While the above-mentioned tests were performed for pulverulent body, the tank diffusion test examines the diffusion leaching characteristics depending on the area, so a sample of which particle is small is to be formed and solidified in a certain shape before the test. Therefore, the results of the tank diffusion test are presented as the leaching of element depending a on surface area function.

Figure 1. pH-stat leaching test

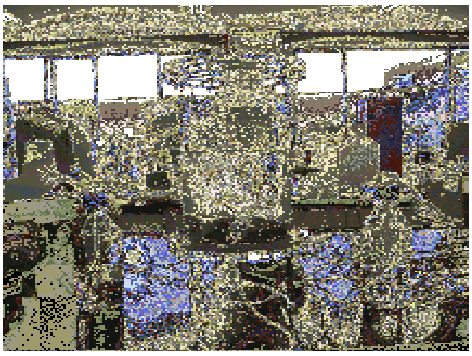

Figure 2. Tank leaching test

However, the accurate surface area of the recycled aggregate is not possible because of the diverse grading and ununiform shape, so a certain amount of the sample was inserted to a reaction cell and it is presented with the leaching of element results depending on the weight. The test is applied to solid waste of which diameter is 40mm and larger. Unlike availability leaching test or pH-stat leaching test, 1,000g of the raw recycled aggregate and 5,000mL distilled water were put into a reaction cell and mixed together(Fig. 2). In 8 hours of the reaction, the reacted water was removed from the cell and the same amount of distilled water was filled again. In 24 hours after the test started, the second reacted water was collected and like this, the accumulative reacted water was collected for 8 times; in 48 hours, 56 hours, 4 days, 9 days, 16 days, 36 days and 64 days.

3. *Element Analysis*

A. *Recycled Aggregate*

After crushing the recycled aggregate with an iron mortar at first, the crushed aggregate was re-crushed smaller than 125μm by using agate-mortar and then, the 200mg of sample was taken. The crushed sample was sealed up in Teflon bomb with 1mL of aqua regia(HNO_3 : HCl 3:1) and heated up at 80℃ for 2 hours. After then, it was cooled down at ambient temperature and neutralized by adding 10mL distilled water and 29mL saturated boric acid solution. Then, it was filtered with a 0.45μm filter

TABLE 2.
CHEMICAL COMPOSITION OF RECYCLED AGGREGATE (Unit:mg/kg)

Ca	Mg	Na	**K**	**Cd**	Pb	Cr
50800	2574	866	8720	7	33	<1ppb
Ni	Zn	Cu	As	Hg	Fe	
22	5852	17	<1ppb	<1ppb	3018	

and analyzed with an atomic absorption spectrometer (Shimadzu AF 6601F).

B. *Ion Analysis*

The reacted water gained from the leaching test was filtered with a 0.45μm filter. After then, the positive ions including heavy metals have been analyzed by using an atomic absorption spectrometer(Analytikajena AAS Vario 6) while the negative ions have been analyzed by using an Ion chromatography (Dionex DX-120).

III. RESULTS AND DISCUSSION

1. *Chemical Properties of the Recycles Aggregate*

The chemical composition of the recycled aggregate is shown in Table 2. Amont major elements, Ca was the most content and followed by Mg, Fe, K and Na. For microelements, Cu and Pb were relatively high content, and Zn was the most contained.

2. *Leaching Test Results*

A. *Serial batch leaching test*

Table 3 shows the results of the batch test using distilled water. pH was relatively high between 10 ~ 11 in both cleaned/not cleaned samples. It is expected that in general, not cleaned sample would have higher concentration of element and especially, much element would be emitted during the initial leaching procedure.

TABLE 3.
LEACHATE CHEMISTRY COLLECTED FROM SERIAL BATCH LEACHING TEST (Non-washed/washed, Unit: mg/l, conductivity: μS/cm)

No. of leachings	**Ca**	**Mg**	**Na**	**K**	**Cd**	**Pb**	**Cr**	**Al**
1	17.6/9.1	0.05/0.16	12.2/18.3	22.2/20.6	0.01/<1 ppb	<1ppb/<1ppb	0.009/0.007	0.06/0.14
2	18.4/10.1	0.05/0.10	4.3/5.5	13.4/13.2	0.02/<1ppb	<1ppb/<1ppb	0.004/0.007	0.04/0.07
3	17.3/11.5	0.05/0.09	2.7/3.6	10.1/10.6	0.02/0.01	<1ppb/<1ppb	0.003/0.003	0.11/0.19
4	19.3/11.5	0.05/0.08	2.0/2.8	8.2/8.8	0.03/0.01	<1ppb/<1ppb	0.003/0.002	0.10/0.10
	Ni	**Zn**	**Cu**	**As**	**Hg**	**Fe**	**Mn**	
1	0.007/0.071	<1ppb/0.006	<1 ppb/0.437	<1ppb/<1ppb	<1ppb/<1ppb	<5 ppb/<5ppb	0.17/0.16	
2	0.009/0.080	<1ppb/<1ppb	<1 ppb/0.032	<1ppb/<1ppb	<1ppb/<1ppb	<5 ppb/<5ppb	0.17/0.16	
3	0.009/0.083	<1ppb/<1ppb	<1 ppb/0.030	<1ppb/<1ppb	<1ppb/<1ppb	<5 ppb/<5ppb	0.17/0.17	
4	0.011/0.077	<1ppb/<1ppb	<1 ppb/0.021	<1ppb/<1ppb	<1ppb/<1ppb	<5 ppb/<5ppb	0.18/0.17	
	pH	**Conductivity**	**F^-**	**Cl^-**	**NO^{3-}**	**PO^{3-}**	**SO_4^{2-}**	**HCO^{3-}**
1	11.14/10.64	418.0/270.5	1.1/1.1	6.7/3.1	6.2/4.7	0.14/<10ppb	28.2/31.9	52.6/67.1
2	11.30/10.67	309.0/180.3	0.3/0.2	2.1/0.3	1.8/1.2	<10	5.3/7.7	39.2/38.9
3	11.20/10.68	325.0/178.6	0.2/0.2	1.3/0.5	0.9/0.7	<10	3.2/5.2	31.7/31.6
4	10.94/10.54	292.5/176.4	0.1/0.1	1.2/0.31	0.8/0.5	<10	2.9/2.9	29.1/28.2

That is, elements would be much dissolved during the initial leaching as the corpuscles attached on the surface contact water. At this moment, contamination load would be reduced by eliminating the element through prior clean-up process.

Ca, K, Na, Cl^- and NO^{3-} were leached more in not cleaned sample, which is supported by the fact that the first leaching sample showed a higher concentration. However, Mg and SO_4^{2-} were showed reverse results, which means the concentrations were higher in the cleaned sample. In case of microelement, the concentration of Cd and Cr was higher in the not cleaned sample, but Ni and Cu showed higher concentration in the cleaned sample. Meanwhile, Mn showed similar concentration in both samples. The other microelements such as Pb, Cu, As and Hg had very low values of concentration under the analysis limitation. The reason why there is the concentration difference between cleaned sample and not cleaned one is probably depending on the locations of elements. That is, the elements(Ca, K, Na and etc) mainly existing on the surface are leached as soon as they contact water. Especially, in case of Cl^- or NO^{3-}, it is not a major component of the recycled aggregate and instead, it is expected that the elements are leached as being absorbed on the particles of aggregate. It is also supported with the fact that the concentration of two elements was sharply reduced after the first leaching(Table 3). However, in case of elements existing inside the particles, not on the surface, they would be leached in a certain time when they contact water. Mg and SO_4^{2-} would the latter case.

The leaching of element depends on the leaching of the element itself as well as the position. In the serial batch test, the leaching procedure of elements, depending on the leaching frequency, is divided into 1) increase(Ca, Cd, Ni), 2) reduction after the max. concentration at first(Mg-washed, Na, K, Cr-washed, Cu-washed, F^-, Cl^-, NO^{3-}, SO_4^{2-}) and 3) maintenance of the relatively proper concentration(Mn). In case the concentration of element is sharply reduced, it is determined that pre-treatment process would reduce the impact on the environment because the concentration would be reduced after the initial leaching. On the other hand, regarding that the concentration increases or maintains as the leaching frequency increases, it is estimated that the element exists inside the aggregate or the balanced concentration is maintained by solid materials to limit the solubility. The solid material to limit element leaching is calculated by earth science modeling. As such, the location of element is the primary cause to affect the leaching characteristics and the reduction by clean-up would be effective only for element existing on the surface.

TABLE 4.
CHEMICAL COMPOSITION OF LEACHATE FROM AVAILABILITY LEACHING TEST (Unit: mg/l)

Ca	Mg	Na	K	Cd	Pb
209.60	2.71	28.1	35.6	<1ppb	0.01
Ni	**Zn**	**Cu**	**As**	**Hg**	**Cr**
0.12	0.95	<1ppb	<1ppb	<1ppb	<1ppb
Fe	**Mn**	**F^-**	**Cl^-**	**PO_3**	**SO_4^{2-}**
0.13	<5 ppb	0.10	1.34	0.15	9.23

B. *Availability leaching test*

The test is performed to calculate the maximum value of sample to be leached. A great quantity of Ca is leached and the other major elements(Mg, Na, K, SO_4^{2-}) are also leached. Regarding microelement, the microelements(Cd, Cu, As, Hg, Cr, Mn) but Pb, Ni and Zn showed the concentration lower then the detection limit(Table 4). Even not under the same conditions, the availability leaching test results showed that all the elements were within the criterion although they were tested under worse condition than the domestic process test or TCLP

TABLE 5.
RESULTS FROM PH-STAT LEACHING TEST (Unit: mg/l)

pH	Ca	Mg	Na	K	Cd	Pb	Cr
4	580.6	3.0	17.0	48.1	0.01	0.14	<1ppb
5	276.0	0.3	20.5	493.5	0.01	0.04	<1ppb
5.5	557.3	4.9	147.8	35.3	0.02	0.01	<1ppb
7	1003.3	23.8	26.8	75.4	0.02	0.04	<1ppb
8	977.3	22.8	17.1	85.4	0.03	<1ppb	<1ppb
9	666.6	4.8	21.2	63.2	0.04	<1ppb	<1ppb
10	555.6	2.3	32.1	57.7	0.00	<1ppb	<1ppb
11	292.4	0.3	6.8	40.0	0.01	<1ppb	<1ppb
12	172.9	0.1	23.0	48.1	0.02	<1ppb	<1ppb
pH	**Ni**	**Zn**	**Cu**	**As**	**Hg**	**Fe**	**Mn**
4	0.16	0.08	0.02	<1ppb	<1ppb	0.30	<5ppb
5	0.15	0.07	0.02	<1ppb	<1ppb	0.13	<5ppb
5.5	0.14	0.08	0.01	<1ppb	<1ppb	0.12	<5ppb
7	0.29	0.08	0.01	<1ppb	<1ppb	0.13	<5ppb
8	0.38	0.08	0.01	<1ppb	<1ppb	0.07	<5ppb
9	0.14	0.08	0.06	<1ppb	<1ppb	0.11	<5ppb
10	0.14	0.09	0.05	<1ppb	<1ppb	0.13	<5ppb
11	0.16	0.09	0.04	<1ppb	<1ppb	0.03	<5ppb
12	0.15	0.09	0.05	<1ppb	<1ppb	0.06	<5ppb

method(lower pH, longer agitation time). Therefore, it is reasonably determined that the recycled aggregate would be a resource to be reclaimed or recycled, not one to be reclaimed as a harmful waste.

C. pH-stat leaching test

pH is an important adjustment factor to affect the solubility of metal elements including microelement. The leaching degree of the recycled aggregate also depends on pH(Table 5, Fig. 3). In case of the microelement, the only Zn, Cu, Cd and Ni were detected and the other microelements showed the concentration lower than the analysis limit. In addition, the max. leaching concentration was also recorded less than the criteria of the domestic waste process test or TCLP. Most heavy metals have more leaching degree as the pH is lower, but the test showed that the only Fe had lower leaching degree as its pH increaes and that Ni and Cd had the most leaching degree when the pH was between 6 ~ 8. On the other hand, it was also found that the leaching degree of Cu sharply increased.

D. Tank Diffusion Test

The results of the reaction totally for 64 days show the following 3 cases; the leaching degree of element is reduced, maintained or slightly increased(Table 6). In the former case, the most element exists on the surface, is leached at first as it contacts water and then, eliminated in a time. However, the case that the leaching degree is maintained may be understood that the leaching of element is adjusted by diffusion.

Fig. 4 shows the changes in the concentration by times of leaching test are compared with the cumulative concentration, total concentration calculated from the analysis of the solid recycled aggregate and the availability leaching test results. The bold line in Fig. 4 shows the total concentration contained in the solid while the thin line means the concentration calculated by the availability leaching test. If an element is leached by diffusion, the element leaching would occur at a uniform speed and may be expressed as a linear equation close to 1.0. However, as seen in the almost elements in the test results, the leaching concentration is reduced every time it is performed and the elements approach to equilibrium status. It may be interpreted that the element is leached much at the initial time and leaching amount of it is reduced as it is gradually exhausted. On the other hand, it is determined that the case(i.e. Zn) the initial leaching is maintained but the speed increases after a point of time would be affected by the changes in the chemical

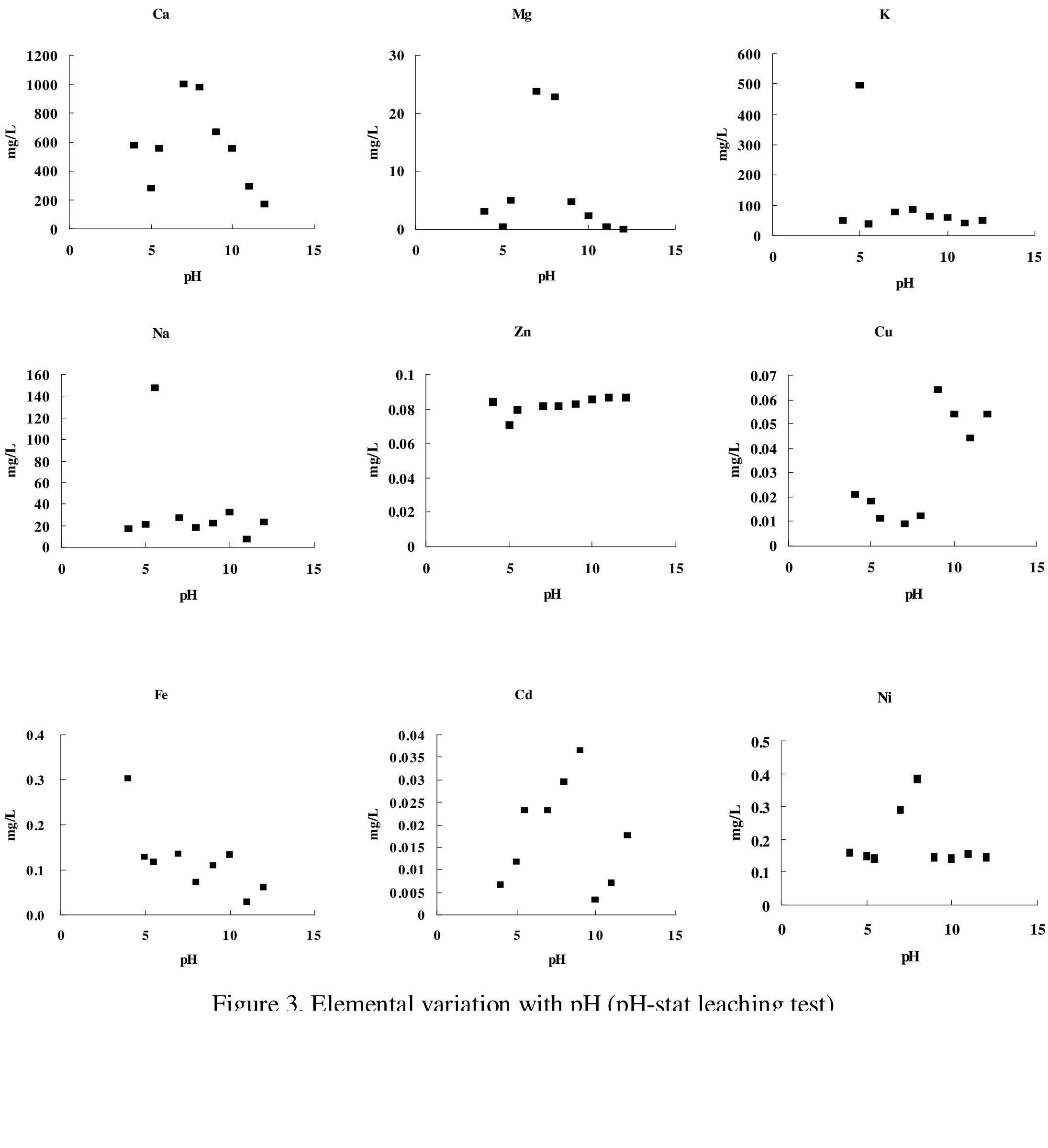

Figure 3. Elemental variation with pH (pH-stat leaching test)

TABLE 6.
AMOUNT OF DIFFUSED ION FROM TANK TEST (Unit: mg/l, conductivity: µS/cm)

Duration (hr)	Ca	Mg	Na	K	Cd	Pb	Cr
8	14.49	0.30	4.72	26.67	<1ppb	0.015	<1ppb
24	12.66	0.13	2.59	43.09	<1ppb	<1ppb	<1ppb
56	18.97	0.17	1.88	38.23	<1ppb	<1ppb	<1ppb
96 (4 days)	0.78	0.06	7.05	31.56	<1ppb	<1ppb	<1ppb
216 (9 days)	6.11	0.07	1.65	12.99	0.021	<1ppb	<1ppb
384 (16 days)	23.87	0.07	6.95	13.73	0.029	<1ppb	<1ppb
864 (32 days)	22.65	0.04	2.07	12.40	0.019	<1ppb	<1ppb
1536 (64 days)	54.89	0.01	1.32	7.42	0.023	<1ppb	<1ppb
Total amount(mg/kg)	770.10	4.22	153.81	930.44	0.46	0.08	N/A
	Ni	**Zn**	**Cu**	**As**	**Hg**	**Fe**	**Mn**
8	0.108	0.062	0.079	<1ppb	0.004	0.08	<5ppb
24	0.100	<1ppb	0.064	<1ppb	0.005	0.10	<5ppb
56	0.140	<1ppb	0.090	<1ppb	0.004	0.19	<5ppb
96	0.052	0.035	0.038	<1ppb	0.004	0.15	<5ppb
216	0.135	0.057	0.051	<1ppb	<1ppb	<5ppb	<5ppb
384	0.098	0.040	0.045	<1ppb	<1ppb	<5ppb	<5ppb
864	0.164	0.025	<1ppb	<1ppb	<1ppb	<5ppb	<5ppb
1536	0.168	0.024	<1ppb	<1ppb	<1ppb	<5ppb	<5ppb
Total amount(mg/kg)	4.83	0.78	1.84	N/A	0.08	3.71	N/A
	pH	**Conductivity**	**F-**	**Cl-**	**NO3**	**PO3**	**SO4**
8	9.78	84.1	0.02	1.12	4.37	0.30	21.88
24	9.42	33.5	0.02	0.66	1.85	<10ppb	13.83
56	9.19	23.2	0.06	0.70	1.82	<10ppb	16.27
96	9.29	22.3	0.01	0.40	0.84	<10ppb	9.00
216	9.26	80.5	0.01	0.32	0.75	<10ppb	9.63
384	8.97	105.6	0.01	0.35	0.50	<10ppb	8.66
864	9.28	48.7	0.02	1.23	0.41	<10ppb	10.31
1536	9.42	33.5	0.01	0.13	0.59	<10ppb	10.00
Total amount(mg/kg)	N/A	N/A	0.80	24.55	55.80	1.50	497.90

conditions having an influence on leaching process(i.e. changes in pH). The mobility of Zn contained in cement may be limited by the mixture of Ca-Zn. The delayed leaching in this test must depend on the leaching of Ca.

Classifying the leaching characteristics of each element, it may be 1) surface leaching: Na, Ni, NO^{3-}, Cl^{-}, 2) elimination of leaching part: Mg, K, Cu, Hg, Pb, 3) diffusion leaching: Ca, Fe, F^{-}, SO_4^{2-} and 4) changes in leaching condition: Zn. Since most micro heavy metals had too low concentration, it was difficult to examine the cumulative leaching characteristics. It was found that most elements but SO_4^{2-} in the tank test showed lower concentration than the availability leaching test, which means that more elements than the results leached in such tests may be leached. However, in case of microelement harmful to the environment(incl. heavy metals), it was determined that the contamination possibility resulting from the leaching of the recycled aggregate would be little because the leached amount was almost as same as the availability leaching test results in case of major elements.

IV. CONCLUSIONS

In conclusion, it may be said that the recycled aggregate would not cause the environmental risk due to leaching of microelement with high environment risk as it contact water. Although the leaching range of element was diverse depending on test methods, the concentration was not beyond the criteria of the waste process test or TCLP of which conditions were not worse than the tests performed in this study. Furthermore, the ratio of water to the recycled aggregate was 3:1 in this study but actually, a river will have a higher ratio between water and solid materials if it flows, almost reaching the unlimited ratio. Therefore, it is also expected that the leached element will be diffused, moved and diluted finally in river water. However, it is determined that the high pH of the recycled aggregate would affect the environment. Fortunately, it was found that the ratio of water: the recycled aggregate which was 3:1 in the serial batch leaching test dropped up to 9 in the tank test, in which the ratio of water: waste was 5:1. Considering that as a difference between both tests, the former was a test agitating at 360° but the latter left it without agitation and that the recycled aggregate used as a scour-protective aggregate in river water would not have any artificial agitation, the pH would be possibly lowered at fields. In addition, Ca and S that significantly contribute to the pH are exhausted slowly than any other element and the leaching is typically limited by diffusion, so the pH would be gradually reduced.

Without any separate harmfulness criteria, the tests in this study have been compared with TCLP test and the domestic waste process test. However, it is probable that

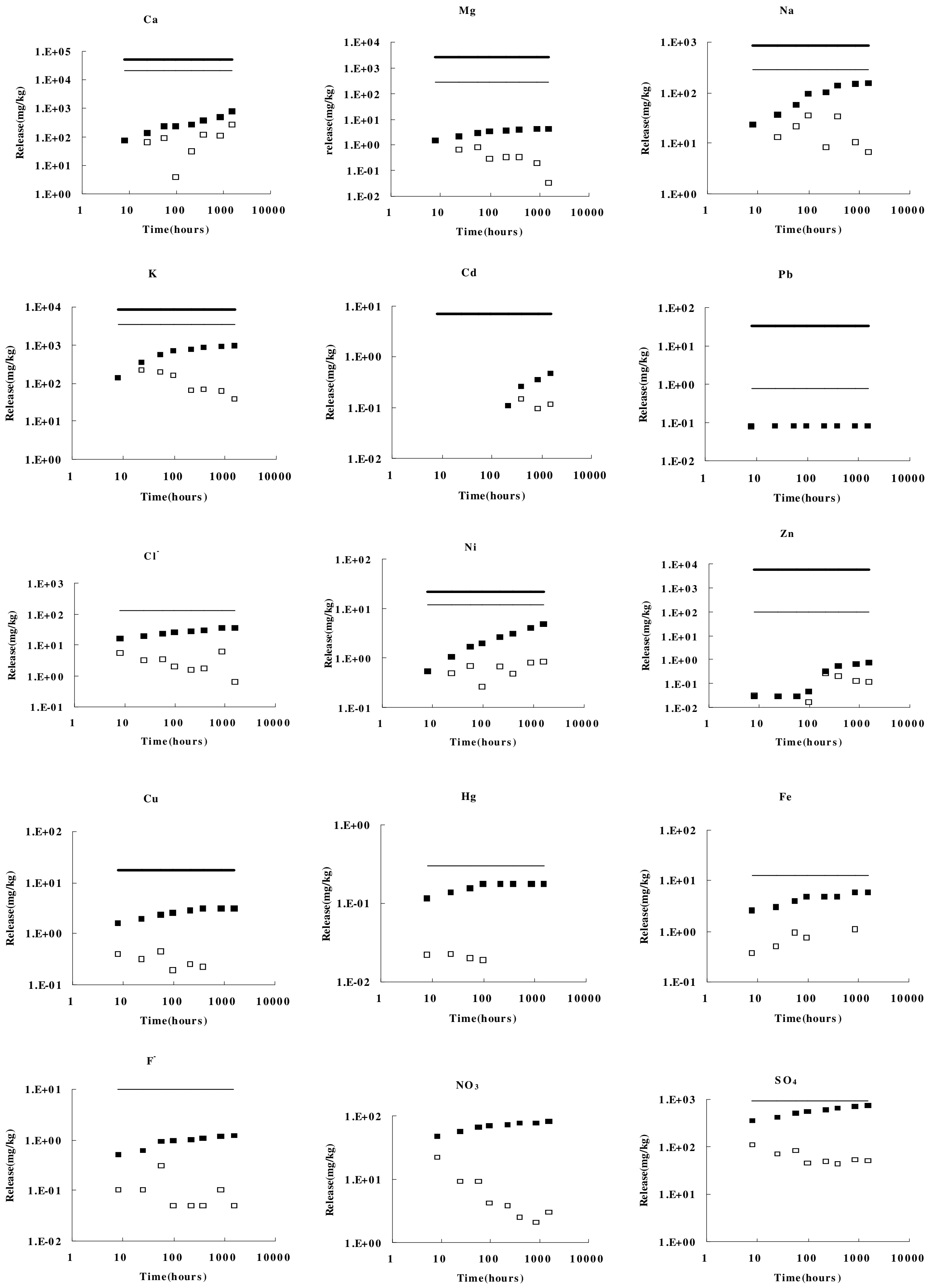

Figure 4. Elemental release from tank leaching test (thin line: availability leaching test, bold line: total contents, open square: leaching from each session, closed square: cumulative release)

little environment risk would be measured or detected as long as the current is much enough. At this case, it is more meaningful to compare the recycled aggregate with other material based on the leaching amount of unit weight, not on the environment risk of the material itself. The total cumulative amount see in Table 6 means the total amount leached from 1kg the recycled aggregate in the tank diffusion test. Based on it, it is possible to assess the leaching potentiality of elements depending on the recycled aggregate used in a river and it may be determined whether the qualitative risk exists under the conditions of a field.

Among the potential environmental occurred when the recycled aggregate is used as a material for protecting bridge foundation against scour, it seems that the environmental risk resulting from the leaching of microelement is little and the use of the recycled aggregate would be reasonable. Despite of no environmental criteria in this study, it is determined that conditionally, the assessment of safety in the aquatic ecosystem affected by minerals when Ca and Mg are plentifully leached should be necessarily considered.

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