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Utilization System of Waste Slurry from Construction Works

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Abstract

A large or great quantity of waste slurry or sludge with high water content is produced during any large scale construction project, and is especially true in foundation work. Therefore, what is required from the environmental geotechnical point of view, is the establishment of method or methods which can make a maximum utilization of these wastes. In this paper, we propose a utilization system for waste slurry, which consists of two treatment methods of dehydration or solidification. The selection of the treatment methods is based on the density and the viscosity of the waste slurry. Through experimental studies, it has been shown that Carbonated-Aluminate Salts, newly developed, and coal fly-ash, a kind of industrial waste, can be used effectively as flocculant and stabilizer in this system and taking the applicability of each method into account, the combination of dehydration and solidification is essential. The proposed system results in efficient treatment, decrease in volume, stabilization, and recycling as resources.

1. Introduction

Human action for "Sustainable Development" is required so that a prosperous civilization can coexist with sound environment. "Environmental geotechnology" has played an important role in conserving our environment based on the standpoint of the construction industry. The waste utilization in construction works can be one of the most effective strategies to solve the problems on waste treatment and resource conservation. Utilization of wastes from various industries, e.g., electric power generation companies and steel manufacturing factories etc., has been well documented$^{1)\sim4)}$. Due to the developments in waste management technology, about half of the industrial wastes are reused in Japan. However, there is still a great need to utilize a large amount of by-products which are generated from various construction projects.

The by-products from construction works can be classified as surplus soil, waste sludge (or slurry), waste concrete or asphalt and so on. In Japan, among all the types of wastes generated mentioned above, the generation of waste slurry or sludge has reached the level of 14,400 Gg a year and about 80% of the material produced is still disposed of without any proper treatment$^{5)}$. This waste slurry is discharged from foundation works such as cast-in-place concrete piles, continuous diaphragm walls, shield tunnel etc. As the need to develop underground space increases, so the quantity of waste slurry or sludge will increase, which will result in the increased frequency of illegal dumping of construction wastes. Further, the disposal sites are being filled faster than the originally predicted time. Due to the reasons given, it is imperative that proper treatment methods of waste slurry be established. The enactment of Law for the Promotion of Utilization of Recyclable Resources (1991) and Treatment Guideline of Construction Wastes (TGCW, 1990) by the Ministry of Health and Welfare of Japan, will stimulate the utilization of the construction wastes.

Properties of waste slurry varies greatly due to the differences in respective origin, excavation methods employed, additive materials etc. Some discharged slurries with high water content can be treated by dehydration resulting in volume decrease, such as the Filter-press method, Roller-press method etc.[6]. Many types of inorganic or organic flocculants have been developed and utilized in many dehydration plants[7]. The application of the dehydration method, however, is not universal because many kinds of waste slurries contain protective colloids which are difficult to separate into water and solid. Moreover, most of the dehydrated cakes have lower strength than the criteria (q_c (cone index measured by cone penetration test) $= 2$ kgf/cm^2 ($= 196$ kPa) or q_u (compressive strength) $= 0.5$ kgf/cm^2 ($= 49$ kPa)) set for TGCW to classify surplus soil and waste slurry, hence are considered as waste and should be disposed of. Methods to solidify sludge with high moisture content by hardening materials without other treatment have been also discussed. The potential use of stabilizers made from industrial wastes or cement group hardening materials as sludge solidification have been elucidated[8]~[12], such traditional solidification methods are not always superior from technical and economical aspects.

From the viewpoint of sludge utilization, some methods have been discussed. Researchers (e.g., Iwai et al[13]) have elucidated that the slags made from sewage sludge by melting have properties suitable for interlocking materials. Tay et al[14] indicated that the product made from sewage sludge mixed with lime by incineration can be utilized as masonry cement, and Kamon and Nontananandh[10] proposed a method to make soil stabilizer from the mixture of some types of industrial waste sludge and lime by incineration. However, these techniques are too expensive to treat the waste sludge or slurry generated during construction.

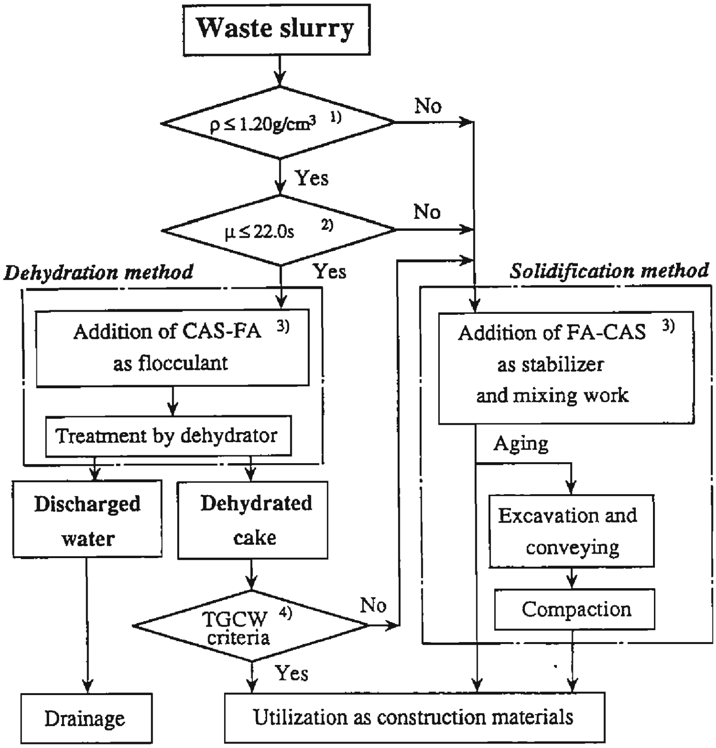
The object of this study is to propose a new utilization system of waste slurry which consists of two treatment methods: (1) dehydration method; and (2) solidification method. To clarify the effectiveness of this system which uses Carbonated-Aluminate Salts (CAS) and coal fly-ash as flocculant or stabilizer, experiments were carried out on some types of waste slurry.

2. New Utilization System of Waste Slurry

2.1 Outline for Utilization System of Waste Slurry

Waste slurry is a mixture of excavated soil and water and is discharged from many kinds of excavation works. Generally, it contains many fine particles and is difficult to dehydrate rapidly. In the case of slurry excavation methods in which bentonite or polymers such as Carboxy-methyl cellulose (CMC) are often used for regulating viscosity, these dispersants remain in the waste slurry. Therefore, the slurry is very difficult to dehydrate. In solidifying slurries, a large amount of stabilizer (e.g., cement) is needed to harden the waste slurry to attain proper strength.

In order to solve these problems we propose a new utilization system for waste slurry[15]. The conceptual outline of the system is shown in Fig. 1. It can be seen that this system consists of parallel dehydration and solidification methods which result in efficiency, decrease in volume, stability, and recycling as resources. In dehydration, it is proposed that the waste slurry, to which Carbonated-Aluminate Salts (CAS) and Fluidized Bed Combustion Coal Ash (FA) are added as flocculants, should be dehydrated with the object of volume reduction. Especially by using a high pressure dehydrator, the dehydrated cakes can easily attain the strength criteria set by TGCW. Therefore, these dehydrated cakes can be utilized directly as embankment and/or subgrade materials. Also the discharged water satisfies the environmental standards in potential of hydrogen



Note

1) ρ : density of waste slurry.

2) μ : funnel viscosity with 500cc-funnel of waste slurry.

3) CAS : Carbonated-Aluminate Salts

FA : Fluidized Bed Combustion Coal Ash

4) TGCW criteria : $q_c \geq 2.0$ kgf/cm^2 (= 196 kPa) or

$q_u \geq 0.5$ kgf/cm^2 (= 49 kPa)

Fig. 1. Outline for utilization system of waste slurry.

(pH) and suspended solids (SS). In the solidification method, it is suggested that the slurry be stabilized by CAS and FA to increase the strength for embankment or subgrade purposes. The use of FA can be very effective from both the technical and economical points of view.

2.2 Selection of Treatment Methods

The selection between the two methods is based on the character of the waste slurry. Founded on the experience gained from dehydration experiments and various kinds of dehydration properties of waste slurries, it has been proposed that the density (ρ) and funnel-viscosity (μ) measured with a 500 ml-funnel can be used as the criteria of selection. These parameters are universally measured to control the character of slurry at the excavation sites. Fig. 2 shows three different kinds of slurries with independent ρ-μ characteristics due to the containment of CMC, bentonite and soil particles. The solid content indicated by the density of slurry and the funnel-viscosity increased by the remaining bentonite and CMC can show the possibility or the effectiveness of dehydration treatment. The attempt on volume reduction by dehydrating a high solid content slurry is not always the best strategy from technical and economical aspects. Slurries with low density can be dehydrated easily. However, if these slurries have a high viscosity due to dispersant remnants, then these slurries are difficult to dehydrate. Given the above parameter, the waste slurry with a ρ-value higher than 1.2 g/cm^3 or a μ-value higher than 22 seconds can be treated effectively by solidification.

2.3 Materials

CAS used as flocculant and stabilizer are differential mixtures of portland cement, $Al_2(SO_4)_3$, Na_2CO_3, $CaSO_4$ and so on (shown in Table 1). In particular, newly developed CAS flocculant has the following properties:

(1) rapid flocculation,
(2) neutrality (pH = 5.0-9.0),
(3) impossibility of contamination by organic matter or chlorine compounds due to its

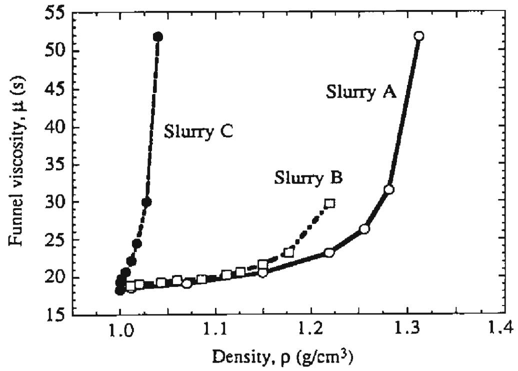


Fig. 2. The relationship between density and viscosity of slurry.

composition,

(4) simple operating management due to non-existence of optimum additive content.

The FA used in this study is derived from a fluidized bed combustion system. FA has gypsum and lime because of the use of desulphurizer and incomplete oxidation reaction in the incineration method. Table 2 shows the properties of the FA used in this study. It is important to assess the environmental impact induced by the utilization of

Table 1. Compositions of Carbonated-Aluminate Salts (CAS)

	CAS stabilizer	CAS flocculant
Portland cement	50%	7%
$Ca(OH)_2$	8%	—
$CaSO_4$	9%	—
$CaCO_3$	—	30%
$Al_2(SO_4)_3$	6%	40%
Na_2CO_3	2%	21%
Blast furnace slag	25%	—
Anionic polymer (FA 50)	—	2%

Table 2. Physical properties and chemical composition of fluidized bed combustion coal ash (FA)

Particle density ρ_s	(g/cm^3)	2.28
Blaine specific surface area	(cm^2/g)	2868
Ignition-loss	(%)	39.2
Chemical composition	(%)	
SiO_2		23.8
Al_2O_3		16.5
CaO		10.8
MgO		1.6
Na_2O		0.2
K_2O		0.3
T-Fe		2.9
SO_3		1.8
C		36.1
Leachate component[1]	(mg/l)	
T-Hg		<0.0005
Cd		<0.01
Pb		0.02
Org-P		<0.01
Cr^{6+}		0.04
As		<0.001
CN^-		<0.01

1) Leachate components were measured through the leachate test settled by the notification of the Environmental Agency.

Table 3. Waste slurry samples used in this study

Sample	Origin
Waste slurry A	shield tunnel work
Waste slurry B	shield tunnel work
Waste slurry C	cast-in-pile concrete pile work
Waste slurry D	mixture of bentonite and water
Waste slurry E	cast-in-pile concrete pile work
Waste water A	sludge dredged in a river
Waste water B	by erosion of laterite ground
Waste water C	muddy pond water

waste material such as FA. The leachate levels of harmful components from FA are very low against the environmental quality standard, and it can, therefore, be utilized effectively in a utilization system for waste slurry without concern about environmental impact.

In order to evaluate the effectiveness of the utilization system, the experimental studies were carried out on waste slurry samples illustrated in Table 3.

3. Dehydration Method by a New Flocculant

3.1 Flocculation and Dehydration Characteristics

The addition of CAS and CAS-FA (the mixture of CAS and FA at a ratio of 5:2) causes the immediate formation of 0.5-1.0 mm diameter flocs and the distinct boundary between solid (flocs) and water, while the slurries with PAC or $Fe_2 (SO_4)_3$ have too small floc to observe the separation of water phase from the slurry. In this case, the slurry has a density lower than 1.1 g/cm^3.

As shown in Fig. 3, the typical floc sedimentation characteristics measured with 1000 ml mess cylinder, CAS and CAS-FA have better improvability in sedimentation than the other flocculants. Though the tendency of sedimentation is less effective and remains unchanged in spite of the variation in additive content of PAC, the increase of CAS and CAS-FA causes the formation of larger flocs and consequently efficient sedimentation. Due to the close relation between additive amount and flocculation, it is considered that CAS is more practical to be used in a dehydration plant from an operational management point of view.

It is important to investigate the durability of flocs formed when the slurry is transported in the dehydration plant. Though the flocs formed by CAS are completely destroyed by 5 minutes of churning in an agitator, flocs are reformed by releasing the slurry from churning. A small decrease in sedimentation velocity is caused by churning as shown in Fig. 3. Nonetheless, it is judged that the flocs produced by CAS and CAS-FA are durable enough to be used in dehydration plant.

The consolidation tests with an oedometer on samples 6 cm in diameter by 6 cm in height were carried out on the sludge sedimented for 30 minutes. In the case of dehydra-

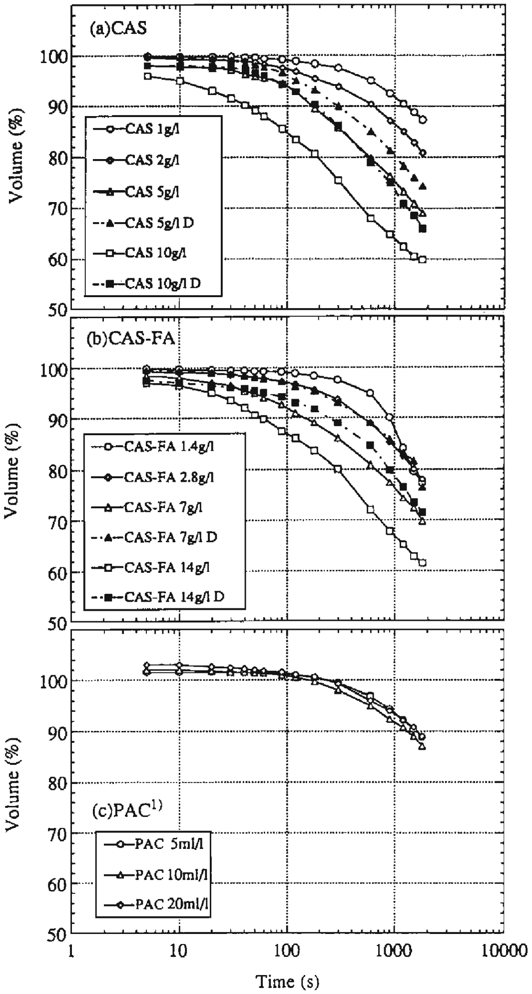


Fig. 3. Sedimentation characteristics of waste slurry A with flocculants.
(Waste slurry A: $\rho = 1.060$ g/cm^3; $\mu = 19.2$s
1): with 10 ml/l addition of Polymer B 0.01% solution
D: the slurries obtained through churning test)

tion of slurry with low density (Fig. 4 (a)), CAS and CAS-FA achieved the dehydration by compression because of the large and strong flocs, while much of the suspended solids were intermixed with discharged water, not having been separated well with PAC (in Table 6). According to examples of compression curves as shown in Fig. 4 (a), it takes 5-10 minutes for the slurry with CAS to reach the final volume by compression, which is applicable to a practical dehydrator.

It is considered that improvability of CAS depends on the level of density of a slurry. In treating high density slurry, shown in Fig. 4 (b), CAS was not more effective

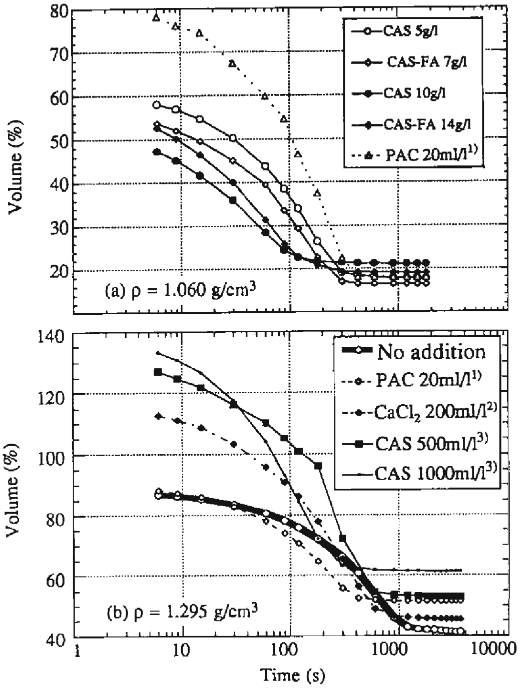


Fig. 4. Consolidation curves of waste slurry A with flocculants.
(Consolidation pressure: 9.8 kPa
1): with 10 ml/l addition of Polymer B 0.01% solution
2): with 20 ml/l addition of Polymer A 0.1% solution
3): 5% CAS solution)

Table 4. Propriety of dehydration by consolidation and consolidation time (Waste slurry B)

Type of flocculant	Additive content	Density of slurry (g/cm^3)			
		1.210	1.184	1.144	1.116
—		40 (87.1)	×	—	—
CAS-FA	28 (g/l)	30 (13.4)	25 (6.4)	×	—
CAS-FA (L)	200 (ml/l)	×	×	12 (347)	8 (345)
PAC[1]	20 (ml/l)	25 (9.0)	15 (133)	—	—
PAC[1]	10 (ml/l)	—	—	12 (6250)	8 (284)

Consolidation pressure : 5.6 kgf/cm^2 (= 549 kPa) (after 0.8 kgf/cm^2 (= 78 kPa) for 5 minutes)

CAS-FA (L) : mixture of CAS-FA and water (14 : 100)

Unbracketed numbers indicate the time (minute) to reach the final volume by compression, and bracketed numbers indicate the SS (mg/l) of discharged water.

1) with 10 ml/l addition of Polymer B 0.01% solution.

Table 5. Propriety of dehydration by consolidation and consolidation time (Waste slurry C)

Type of flocculant	Additive content	Density of slurry (g/cm^3)				
		1.038	1.020	1.015	1.004	1.001
—		×	—	—	—	—
CAS	20 (g/l)	×	—	—	—	—
CAS(L)	600 (ml/l)	—	—	×	9 (215)	9 (0.5)
CAS(L)	200 (ml/l)	×	×	×	×	×
PAC	40 (ml/l)	×	×	×	×	×
	40 (ml/l)1)	×	×	12 (1569)	8 (4.7)	8 (59.6)
	10 (ml/l)	×	×	×	8 (3.7)	×
	10 (ml/l)1)	×	×	×	8 (5.8)	7 (9.7)
$Fe_2(SO_4)_3$	200 (ml/l)	×	×	×	×	×
	200 (ml/l)1)	×	×	13 (15.8)	8 (1.8)	7 (4.7)

Consolidation pressure : 5.6 kgf/cm^2 (= 549 kPa) (after 0.8 kgf/cm^2 (= 78 kPa) for 5 minutes)
CAS (L) : mixture of CAS and water (10 : 100)
Unbracketed numbers indicate the time (minute) to reach the final volume by compression, and bracketed numbers indicate the SS (mg/l) of discharged water.
1) with 500 ml/l addition of Polymer A 0.1 % solution.

than the other flocculants. Tables 3 and 4 indicates the possibility of dehydrating slurries by consolidation with various levels in density. The samples marked x in the tables flocculated too insufficiently to consolidate. CAS contributes the improvability of low density slurry (Table 4). In the case of a slurry with high viscosity due to the remnants of CMC or bentonite, though it has low density, the flocculation will not come about by adding CAS (Table 5). In order to dehydrate the slurries containing bentonite, the bentonite must gel by the addition of flocculants. PAC and $Fe_2\ (SO_4)_3$ can make the bentonite to gel due to cation exchange, and, therefore, are more effective in the dehydration of bentonite slurry than is CAS. It is concluded that the treatment of the slurries with high density or high viscosity by the dehydration method is very difficult, from the technical as well as the economical.

3.2 Properties of Dehydrated Cake

Figs. 5 and 6 show the qc values translated from fall-cone penetration (60° of tip angle and 60 g of mass) of the cakes dehydrated by a small-sized Filter-press test[16]. In the Filter-press system, at an air pressure of 686 kPa the slurry (3000-5000 ml) was poured with flocculant into one filtration compartment of 12 cm in diameter and 3 cm in height for 60 minutes. When treating slurry B, the cakes treated by CAS have as high or higher strength than the ones by the other flocculants. In the case of a slurry which contains bentonite, the cakes by CAS are much lower in strength because of insufficient flocculation as stated above.

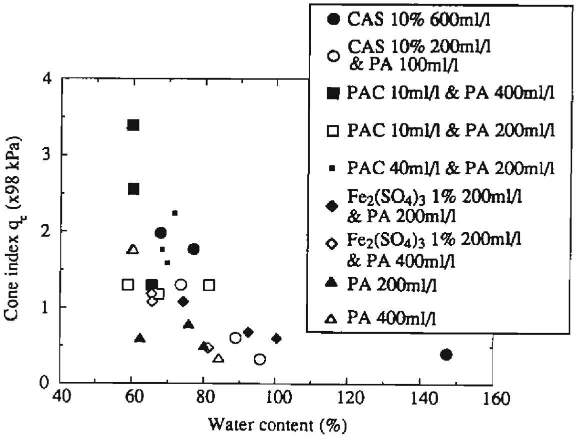


Fig. 5. Strength characteristics of cakes dehydrated by small-sized Filter-press test. (Waste slurry B: $\rho = 1.150$ g/cm^3; $\mu = 21.5$s
PA : with addition of Polymer A 0.1%)

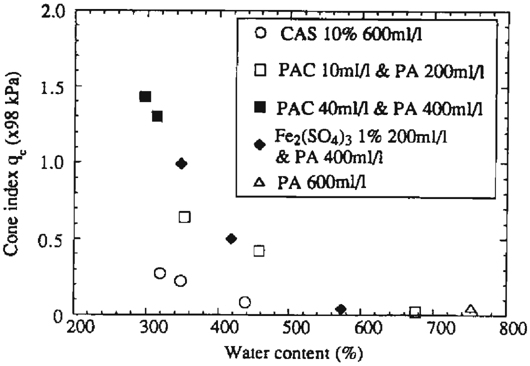


Fig. 6. Strength characteristics of cakes dehydrated by small-sized Filter-press test. (Waste slurry D: $\rho = 1.011$ g/cm^3; $\mu = 20.2$s
PA: with addition of Polymer A 0.1%)

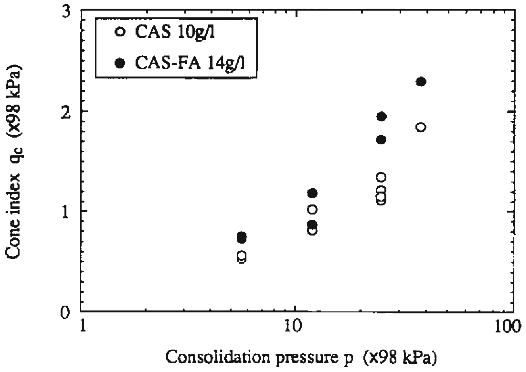


Fig. 7. Strength characteristics of dehydrated cakes. (Waste slurry A: $\rho = 1.060$ g/cm^3; $\mu = 19.2$s)

It must be noticed that the q_c values translated from fall-cone penetration differs from the one of TGCW criteria (q_c = 2kgf/cm^2 = 196k Pa). Most of the cakes obtained from the Small-sized Filter-press test can not reach the TGCW criteria for utilization as reclaimed resources. However, based on the experimental research on the relationship between q_u and fall-cone penetration of the cakes dehydrated by Filter-press and Roller-press system[6], compressive strength 0.5 kgf/cm^2 (= 49 kPa), another TGCW criteria, corresponds to about 2 mm of fall-cone penetration, which is translated to 140 kPa of q_c. Therefore, the dehydrated soil cakes treated by CAS can be utilized for embankment or reclamation.

Table 6. Quality of water discharged by sedimentation and consolidation test

Sample	Type of Flocculant	Additive content	Polymer additive content	Type of experiment[1]	SS (mg/l)	pH
Waste slurry A (ρ=1.06g/cm^3)	CAS	1.0(g/l)	—	S	2.6	—
		2.0(g/l)	—	S	1.8	—
		10.0(g/l)	—	S	3.5	—
	CAS-FA	1.4(g/l)	—	S	1.4	—
		2.8(g/l)	—	S	1.4	—
		14.0(g/l)	—	S	3.0	—
	PAC	20.0(ml/l)	10(ml/l)[2]	S	428.4	—
	CAS	10.0(g/l)	—	C	2.1	7.5
	CAS-FA	14.0(g/l)	—	C	4.0	7.8
	PAC	20.0(ml/l)	10(ml/l)[2]	C	5644.3	4.4
Waste slurry B (ρ=1.15g/cm^3)	CAS(L)	600(ml/l)	—	F	11.4	7.4
		200(ml/l)	100(ml/l)[3]	F	27.6	7.6
	PAC	10(ml/l)	400(ml/l)[3]	F	13.4	6.8
		10(ml/l)	200(ml/l)[3]	F	168	7.0
		40(ml/l)	200(ml/l)[3]	F	380	6.4
	$Fe_2(SO_4)_3$	200(ml/l)	200(ml/l)[3]	F	0.1	7.0
		200(ml/l)	400(ml/l)[3]	F	15.8	7.0
Waste water A	no addition	—	—	S	756.6	6.2
	CAS	0.1 (g/l)	—	S	9.1	6.8
		0.5 (g/l)	—	S	2.9	6.9
	$Fe_2(SO_4)_3$	0.1 (g/l)	50(ml/l)[3]	S	304.8	4.3
		0.5 (g/l)	50(ml/l)[3]	S	140.8	3.5
Waste water B	CAS	0.10(g/l)	—	S	37	7.3
		0.15(g/l)	—	S	31	7.2
		0.20(g/l)	—	S	57	6.9
	PAC	1(ml/l)	10(ml/l)[2]	S	5	7.0
		5(ml/l)	10(ml/l)[2]	S	158	4.4
		10(ml/l)	10(ml/l)[2]	S	468	4.1

1) S : sedimentation test, C : consolidation test, F : small-sized Filter-press test.

2) Polymer B 0.01% solution

3) Polymer A 0.1% solution

Table 7. Quality of waste water treated by CAS (Waste water C)

		Laboratory test		Field test	
		untreated	treated	untreated	treated
pH		7.0	6.9	7.6	7.4
COD	(mg/l)	7.5	4.0	2.6	1.0
BOD	(mg/l)	3.0	1.0	4.0	2.0
T-N	(mg/l)	8.7	0.9	0.75	0.57
T-P	(mg/l)	0.19	0.02	0.11	0.01
T-Fe	(mg/l)	1.9	0.09	1.7	0.52
Ca^{2+}	(mg/l)	9.6	16	8.6	19
Turbidity	(degree)			37	6

There are some strategies to obtain cakes with higher strength. The dehydrated cakes treated by CAS-FA have higher q_c values than the cakes by CAS only as shown in Fig. 7. In this case, the q_c of the cakes with CAS-FA consolidated by high pressure (2.5 MPa) reaches the criteria set by TGCW. Though the dehydration pressures in common dehydrator plants are equivalent to 0.5-1 MPa, the new Filter-press plant which achieves dehydration by a high pressure of 4M Pa has been developed. So the combination of CAS-FA with the high pressure Filter-press plant can produce a dehydrated cake directly utilizable as embankment or subgrade material.

3.3 Properties of Discharged Water

In using CAS as flocculant, the supernatant water and the discharged water satisfy the environmental quality standards (pH and SS) as shown in Table 6. The lack of turbidity of the discharged water depends on the effect of flocculant inducing flocculation. Because CAS flocs itself and the formed flocs incorporate the suspended soil particles, there are few SS remaining in the supernatant water. Due to the effect of cation exchange, the discharged water treated by PAC and $Fe_2(SO_4)_3$ is both turbid and acidic. It is feared that in using PAC in a Filter-press plant excessive compression can result in turbidity of discharged water. It has been confirmed that the utilization of CAS contributes to the water purification, such as BOD (biochemical oxygen demand), N (nitrogen), P (phosphorus), shown in Table 7. Naturally, not only these indexes but also the heavy metals and other harmful components must be considered. Because it is merely that the waste slurry has harmful composition, the dehydration method does not discharge the harmful treated water due to the leachate components of FA and the well-known composition of CAS.

3.4 Application of Dehydration Method

CAS as flocculant has been used at some construction sites on experimental basis and the following advantages have been observed: simple execution management, peel-off characteristics of dehydrated cake from filter cloth, and dehydration characteristics because of the low viscosity of the slurry with CAS.

4. Solidification Method by Coal Ash Utilization

4.1 Strength Characteristics

Table 8 illustrates the changes in strength of waste slurry discharged from a cast-in-place concrete pile work, mixed with FA and CAS. In case of CAS only, the strength required by TGCW can not be achieved at 7 days curing even if the CAS content is raised as high as 25%. The strength of the waste slurry reaches 49 kPa, a criteria set by TGCW, when using 70% FA-13% CAS mixture cured for only 3 days. For embankment or subgrade purposes, it is suggested that the strength after 7 days curing should be able to sustain a 100-200 kPa stress, and the required strength can be achieved when the FA content and the CAS content are more than 40% and 10% respectively. The decrease in the FA content and/or the increase in the CAS content results in the larger

Table 8. Strengths of the slurry-FA-CAS mixtures

Additive content (%)		Compressive strength (kPa)				Volume change ratio
FA	CAS	3 days	7 days	14 days	28 days	
40	7	—	65	199	228	1.20
	10	—	101	356	435	1.22
	13	19	142	629	761	1.24
50	4	—	73	172	219	1.26
	7	—	112	348	314	1.27
	10	15	175	534	665	1.28
	13	29	213	931	855	1.31
60	4	—	123	253	419	1.31
	7	—	194	411	637	1.32
	10	27	282	670	978	1.33
	13	40	396	1145	1381	1.34
70	4	15	215	493	467	1.36
	7	17	319	720	891	1.37
	10	38	435	980	1178	1.38
	13	61	579	1260	1711	1.39
—	10	—	13	15	30	1.02
	20	—	26	40	74	1.09
	25	—	40	67	98	1.10
	30	—	133	183	305	1.17

Waste slurry C : $\rho = 1.040$ g/cm^3, $\mu = 51.7$s

1) Volume ratio indicates the volume of slurry-FA-CAS mixture after mixing versus the one of waste slurry only.

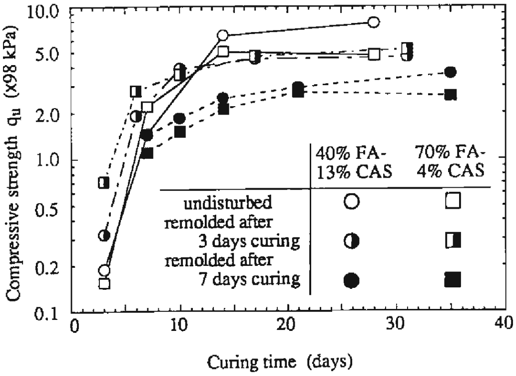


Fig. 8. Strength characteristics of remolded slurry FA-CAS-mixtures. (Waste slurry C: ρ = 1.040 g/cm^3; μ = 51.7s)

growth in strength versus aging period. Therefore, it is possible to attain both early and later strength by adjusting the contents of FA and CAS.

In this treatment method, the addition of FA and CAS results in the volume increase of 20-40%, as shown in Table 7. This volume increase is relatively small compared to the additive amount of FA, giving this method great efficiency from the viewpoint of coal ash utilization.

4.2 Durability Characteristics

Fig. 8 shows comparison of strengths of samples remolded after 3 or 7 days curing with undisturbed samples. Because of the increase in density due to remolding and the incomplete hardening reaction, the mixtures remolded after 3 days curing have higher strength in early stages than the samples cured normally, namely 100-200 kPa strength after 3 days curing after remolding and can be considered for utilization as embankment or subgrade materials. In the soaking test on the samples cured normally for 7 days, the collapse or the softening of the mixtures did not occur. Therefore, the slurry-FA-CAS mixture can be used very effectively as ground material through the process of mixing, hardening, excavating, conveying, and compacting, taking durability into consideration.

4.3 Mixing Workability

In using CAS only, it is difficult to obtain homogeneous mixtures due to the high viscosity of slurry. The slurry-FA-CA mixture is uniform because of the affinity between slurry and FA.

The full scale tank test was carried out to investigate the application of this solidification method in practice. Two tanks, 2.3 m × 8.0 m width × 1.6 m depth were used, and a back hoe with an exclusive dipper (0.7 m^3 volume) adjacent to the tank conducted mixing work. As the total volume of waste slurry discharged from a cast-in-place concrete pile work was 12 m^3, based on our previous experimental experience, it was decid-

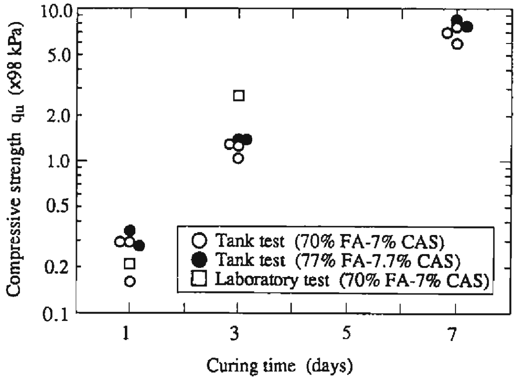


Fig. 9. Strengths of specimens sampled through the tank tests. (Waste slurry E: $\rho = 1.050$ g/cm^3; $\mu = 22.7$s)

ed that the additive contents in the tanks were to be 70% (8400 kg) FA and 7% (840 kg) CAS, and 77% (9200 kg) FA and 7.7% (920 kg) CAS for each tank. After mixing for 40 minutes, the mixtures were kept undisturbed for 24 hours, 3 days, and 7 days. The strength gained by the mixture left for 24 hours was strong enough to permit a safely walking on it. Fig. 9 shows the strengths of specimens sampled at various points in the tanks. The strength dispersion of samples is within a small range in spite of the expected roughness of mixing work because of the size of the dipper versus the tank. The ratio of the strengths sampled in the tanks versus that of the laboratory specimens is very high compared with the ratios in the case of the traditional soil stabilization. The strengths at 3 and 7 days curing are more than 100 kPa and 500 kPa, respectively. The mixture has the potential to be utilized as embankment and subgrade material.

4.4 Application of Solidification Method

The proposed solidification method cannot satisfy the decrease in volume. In order to treat the waste slurry with high density or high viscosity, coal-ash utilization, however, leads to the efficient and rapid treatment, and is desirable from the viewpoint of recycling resources.

5. Conclusions

The main results of this study can be summarized as follows:

(1) The authors propose a system utilizing waste slurry which consists of dehydration or solidification, and found that density (ρ) and funnel-viscosity (μ) of the waste slurry can be used effectively as the indexes to judge against the criteria whether a slurry should be best treated by dehydration or solidification for recycling use.

(2) Carbonated-Aluminate Salts (CAS) as flocculant in this system can form large and durable flocs rapidly. The flocs formed can be easily dehydrated and the discharged water is clear enough to satisfy environmental quality standards. Furthermore, the

combination of CAS and Fluidized Bed Combustion Coal Ash (FA) with the operation of the high pressure dehydrator can produce cakes which can be directly utilized as embankment or subgrade materials.

(3) Solidification method by being mixed with FA and CAS is very effective in treating the high density or high viscosity waste slurry. The well-mixed waste slurry with stabilizers is highly homogeneous and reasonably strong. It also has high durability under the soaking or remolding conditions, so it can be used effectively as embankment or subgrade material.

The utilization system can be practicable from the viewpoint of complete utilization of waste slurry as construction material.

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References

1) Gidley, J.S. and W. S. Sack: Environmental Aspects of Waste Utilization in Construction, *Jour. Environmental Engineering Div., ASCE*, Vol. 110, No. 6, 1984, pp. 1117-1133.
2) Mehta, P.K.: Pozzolanic and Cementituous By-Products in Concrete-Another Look, *Proc. 3rd Int. Conf. on Fly Ash, Silica Fume, Slag, and natural pozzolans in concrete*, Trondheim, Norway, Vol. 1, 1989, pp. 1-43.
3) Kamon, M., S. Nontananandh, and S. Tomohisa: Environmental Geotechnology for Potential Waste Utilization, *Proc. 9 th Asian Resional Conf., SMFE*, Bangkok, 1991, pp. 397-400.
4) Kamon, M.: Definition of Environmental Geotechnology, Environmental Control and Waste Disposal," *Proc. 12th Int. Conf. on Soil Mech. and Foundation Eng.*, Rio de Janeiro, Vol. 5, 1992, pp. 3126-3130.
5) Kutara, K.: The Present State and Future Trend on Disposal of By-Products from Construction and Utilization of Recycled Materials, *Civil Engineering Journal, Public Works Research Institute, Ministry of Construction*, Vol. 34, No. 11, 1992, pp. 32-39 (in Japanese).
6) Kita, D. and H. Tsuji: Treatment and Utilization of Discharged Slurry from Slurry Excavation Methods, *Tsuchi-to-Kiso, JSSMFE*, Vol. 29, No. 11, 1981, pp. 57-64 (in Japanese).
7) Sugawara, M., T. Horinaka, N. Kawaguchi and A. Kitamura: Dehydration Treatment of Surplus Soil and Sludge from Construction Works, *Proc. 47 th Japan National Conf. on Civil Engineering, JSCE*, Vol. III, 1992, pp. 1090-1091 (in Japanese).
8) Kamon, M., K. Sawa and S. Tomohisa: On Stabilization of Hedoro by Using Cement Group Hardening Materials, *Jour. of the Society of Material Science, Japan*, Vol. 38, No. 432, 1989, pp. 1092-1097 (in Japanese).
9) Kamon, M. and S. Nontananandh: Contribution of Stainless-Steel Slag to the Development of Strength for Seabed Hedoro, *Soils and Foundations*, Vol. 30, No. 4, 1990, pp. 63-72.
10) Kamon, M. and S. Nontananandh: Combining Industrial Wastes with Lime for Soil Stabilization, *Jour. Geotechnical Engineering Div., ASCE*, Vol. 117, No. 1, 1991, pp. 1-17.
11) Kamon, M. and T. Katsumi: Effective Utilization of Sludge as Construction Materials by Solidification, *Annuals, Disas. Prev. Res. Inst., Kyoto Univ.*, No. 35 B-2, 1992, pp. 267-287 (in Japanese).
12) Kamon, M., S. Nontananandh and T. Katsumi: Utilization of Stainless-Steel Slag by Cement Hardening, *Soils and Foundations*, Vol. 33, No. 3, 1993, pp. 118-129.
13) Iwai, S., Y. Miura and T. Kawakatsu: New Process of Sewage Sludge Treatment and Utilization of Slag for Construction Materials, *Environmental Geotechnics and Problematic Soils and Rocks, Balkema*, 1987, pp. 447-459.

14) Tay, J. H., and K. Y. Show: Properties of Cement Made from Sludge, *Jour. Environmental Engineering Div., ASCE*, Vol. 117, No. 2, 1991, pp. 236-246.

15) Kamon, M. and T. Katsumi: Utilization of Waste Slurry from Construction Works, *Proc. 13 th Int. Conf. on Soil Mech. and Foundation Eng.*, New Delhi, 1994, pp. 1613-1616.

16) Kamon, M., T. Katsumi and H. Imanishi: Treatment and Utilization of Waste Slurry from Construction Works, *Annuals, Disas. Prev. Res. Inst., Kyoto Univ.*, No. 36, 1993, pp. 37-51 (in Japanese).