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The pilot study on reclamation of incineration ashes of municipal waste in the demonstrative factory

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Abstract: In Taiwan there are 21 Municipal Solid Waste Incinerators (MSWI) built to treat 80% of the MSW nationwide. Approximately 2,000 tons of incineration ashes of municipal waste contain reaction ash and fly ash (3:1 by weight)will be produced daily, and this may cause a serious waste problem.

According to EPA regulations, reaction ash and fly ash produced after incineration should be properly treated. Landfill capacity barely meets the general demands. More efficient actions should be planned and taken. The study found "reclamation" should be the optimal solution to this problem. Only limited research and previous successful experiences are available among other countries. An incinerator in Northern Taiwan is chosen for this study to make environmental bricks from the reaction ash and fly ash. From the previous tests, the results of strength test were measured. From the previous test results, the fly ash products have not reached the desired strength; hence, reaction ash is chosen for further pilot study.

In the experiment, incineration ashes, cement and gravel are mixed in the ratio of 1 : 1 : 1 (by weight), to ground concretization aggregate and pelletization aggregate, the concrete products made from the aggregates were of the strength of 108 kgf/cm^2 and 142 kgf/cm^2 individually. For the purpose of making nonstructural walls which met the State Building Standards. In the study, 50 tons of concrete products was yielded from aggregate and environmental bricks. Further observation and supervision are recommended to ascertain the resource recycling and reclamation.

EPA has planned to build three "Recycling Plants" in northern, middle and southern Taiwan to develop efficient techniques to produce concrete products, sub-base course, soundproofing wall, gravel, artificial fishing reefs, tiles, drainage, bricks and etc. This experiment of the demonstrative plant solves the problem of the incineration ashes and opens another opportunity to reclaim them.

1. Introduction

Based on the previous studies on reclamation of municipal waste ash, the optimal formula of ash, cement, and sand has been established. In this pilot study, "T factory" located in Taipei County was being investigated. This experiment offers further information for reclamation of municipal waste ash.

This study focused on the reclamation of reaction ash of incinerated municipal waste and techniques of concretization and pelletization were being studied. With these techniques, the reaction ash of incinerated municipal waste can be reclaimed and utilized as artificial aggregate and recycle bricks. The TCLP results of these products meet the EPA standards in Taiwan and the strength is also strong enough to be used as non-structural building material. In this study, 50 tons of products were yielded for display use and further experiments and observation.

2. Procedure And Methods

Procedure

The T factory in this study is located in Taipei County. The main structure is composed of two trailers next to the incineration of T factory (see picture 1). One is used for mixing and another is for curing. Other facilities include a sample tank, conveyer belt, mixer, vacuum cleaner and cast. The space between two trailers is used for storage. From the previous tests, the results of strength test were studied. Due to the insufficient strength of fly ash, only reaction ash was chosen for this pilot study.

Picture 1. The outward appearance of the demonstrative factory.

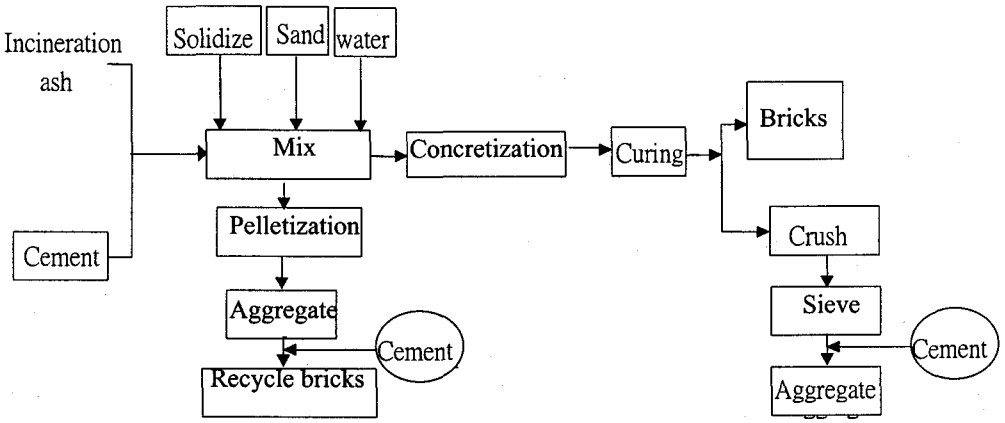

Fig. 1. Procedure of reclamation in the demonstrative factory.

Methods

* Concretization

In this procedure, mix incineration ash, cement, and sand in the ratio of 1:1:1. (The ratio of water to cement is 3:1) Then pour the mixture into molds of 10cm x20 cm x 40 cm to make molded blocks for drying and curing for four hours, 24 hours, 72 hours, 14 days, and 28 days.

The cured blocks were crushed to make concretization aggregate. Put the aggregate back to the mixer along with cement, sand and water (1:1:1). Pour the mix back to the mold to make blocks for further curing process for 28 day. The recycle bricks are made.

The water absorption rate and particle strength are determined and recorded. The aggregate was also tested by running TCLP and Test for Resistance to Abrasion of Small Size Coarse Aggregate.

* Pelletization

In this procedure, mix incineration ash with water and solidizer in the pelletizer. Each sample was dried and cured for seven days, 14 days and 28 days to produce pelletization aggregate. Place the aggregate with cement, sand and water in a mixer, and then pour into a mold to make recycle bricks.

The water absorption rate and particle strength are determined and recorded. The aggregate was also tested by running TCLP and Test for Resistance to Abrasion of Small Size Coarse Aggregate.

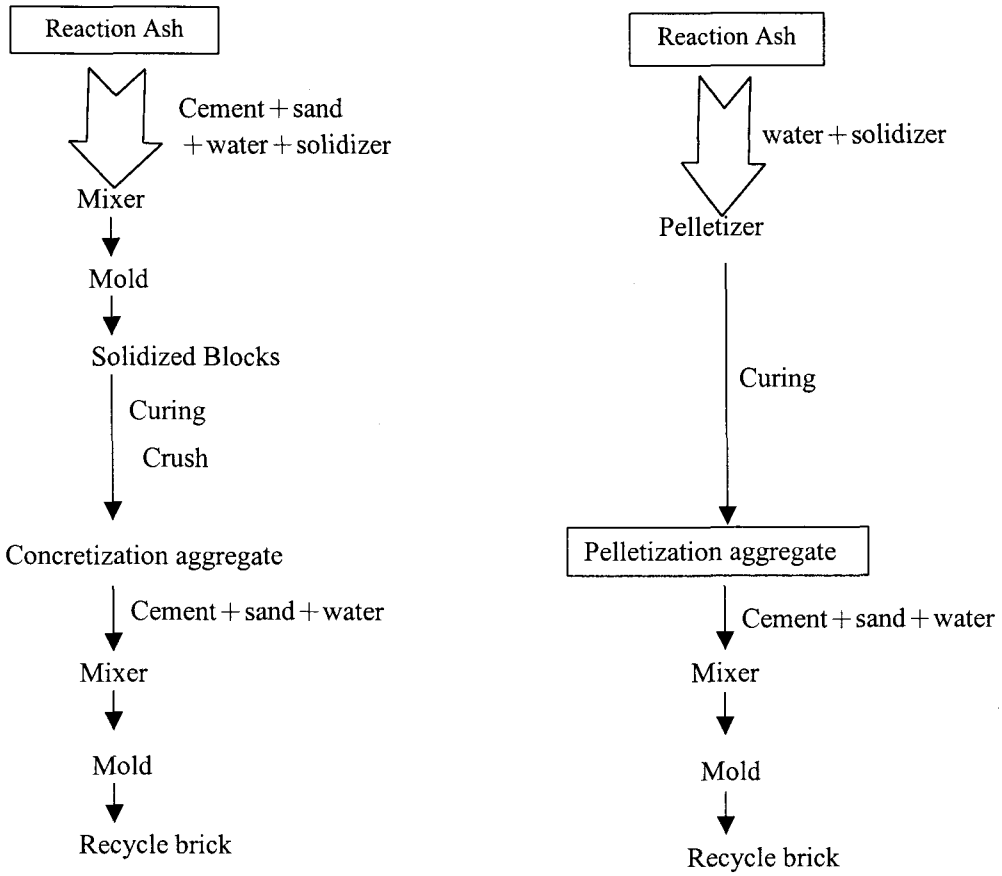

Fig. 2. Procedure of Concretization and Pelletization.

Concretization aggregate and pelletization aggregate is mixed with sand, water, and cement separately to produce two groups (made from concretization aggregate or pelletization aggregate) of recycle bricks. Two groups of bricks are cured for seven days, 14 days, and 28 days. Three brick samples are selected randomly from each group for anti-pressure strength and TCLP.

3. Tests and Results

A. Chemical Properties

(1) Composition Analysis:

The reaction ash sample was analyzed for its chemical composition in order to determine its applicability. The ash was tested by running Methods for chemical analysis of refractory bricks and refractory mortars (JISR2212), Method of Chemical Analysis for Silicon in Metallic Silicon, (Weight Method) (CNS8280), Determination of anions by Ion Chromatography (NIEA W417.50T), Atomic Absorption Spectrum (NIEA W310.50A) and Method of Chemical Analysis for Sulfur in Metallic Silicon (Weight Method) (CNS8287). The results are as followed,

Table 1. Tests and Analysis of reaction ash.

Compositions	Test	Standard No.
LOI	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
SiO_2	Method of Chemical Analysis for Silicon in Metallic Silicon, (Weight Method)	CNS8280
CaO	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212

MgO	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
K_2O	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
Na_2O	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
Al_2O_3	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
Fe_2O_3	Methods for chemical analysis of refractory bricks and refractory mortars	JIS-R2212
Cl	Determination of anions by Ion Chromatography	NIEA W417.50T
Pb	Atomic Absorption Spectrum	NIEA W306.50A
Hg	Atomic Absorption Spectrum	NIEA W306.50A
Cd	Atomic Absorption Spectrum	NIEA W306.50A
Cr	Atomic Absorption Spectrum	NIEA W306.50A
As	Atomic Absorption Spectrum	NIEA W306.50A
SO_3	Method of Chemical Analysis for Sulfur in Metallic Silicon (Weight Method)	CNS8287

After incineration, $CaCO_3$, silicon gel, and active carbon were added to the reaction ash in the bag house. The value of L.O.I (Loss of ignition) and the amount of CaO, Pb and Cl have increased significantly. The test results are shown below:

Table 2. Chemical Analysis of Reaction Ash. Unit : %

Item	Reaction Ash	
	(90.1.11)	(90.3.23)
LOI	37.49	35.50
SiO_2	10.93	3.98
CaO	35.54	42.50
MgO	0.62	1.00
K_2O	3.01	6.02
Na_2O	2.83	6.34
Al_2O_3	0.36	0.81
Fe_2O_3	0.26	0.41
Cl	29.11	27.91
Pb	0.39	0.73
Hg	0.031	0.116
Cd	0.023	0.040
Cr	0.003	0.008
As	0.08	0.018
SO_3	3.66	7.70

Note: 5Kg of reaction ash samples were selected randomly for each test. The test was being duplicated to increase its reliability (the test results are the mean of two tests).

From the analysis, the total weight of SiO_2, Al_2O_3 and Fe_2O_3 is less than 50% of ash composition. In order to solidize the reaction ash, $CaCO_3$ or $Ca(OH)_2$ was added. In this test, Pozzolan cement was added to solidize the aggregate and sulfurides were added to stabilize the bonding between heavy metals (PbS, CdS etc.).

(2) Dioxins Test (the following tests are run on the products)

The reaction ash and brick samples are tested by Dioxins Test (US EPA 1613B). Reaction ash was mixed with sand and water (1:1:1), the amount of dioxins was lowered to 52 pg. The amount of dioxins has been decreased by 93% before concretization.
The results are shown as followed.

Table 3. Dioxins Test result (The Reaction ash before and after solidification).

Sample	Dioxins value(pg/g)
Reaction ash	773
Brick samples	52

Note: The formula of brick samples is "reaction ash : sand : cement = 1 : 1 : 1" (by weight.)

(3) Multiple Extraction Procedure: MEP

Multiple Extraction Procedure (MEP) was conducted based on USA,EPA "Extraction Procedure Toxicity Test" (Method 1310, Chapter 8). "Multiple extraction procedure" (Method 1320) is to simulate the improper landfill treatment on solid waste as well as the elutriation of acid rain that washes out the heavy metal contents from the tested products.

The composition analysis of the solidification product from Multiple extraction procedure
The reaction ash sample was being cured for 28 days. The products were tested with MEP. Heavy metal elements such as Zn and Cu were detected. After the third extraction, the concentration had become insignificant to the device detection. The concentration of Heavy metal ions such as Pb, Cr and Cd had raised the maximum value is still under the EPA limits. Hence it is safe to conclude that this product is stable and capable of resisting the corrosion of acid rain. The results of MEP are shown as followed.

Table 4. The composition analysis of solidification products from Multiple extraction procedure.

Extraction	Initial pH	Zn(ppm)	Pb(ppm)	Cr(ppm)	Cu(ppm)	Cd(ppm)	Final pH
1st	5.0±0.2	0.038	0.453	0.088	0.042	0.055	11.63
2nd	3.00	0.008	0.078	0.067	0.014	0.001	11.68
3rd	3.01	-	0.023	0.088	-	0.003	11.55
4th	3.01	-	0.038	0.097	-	0.003	11.46
5th	3.00	-	0.048	0.127	-	0.005	11.39
6th	3.00	-	0.062	0.139	-	0.004	11.22
7th	3.01	-	0.082	0.166	-	0.003	11.29
8th	2.99	-	0.092	0.171	-	0.004	11.07
9th	2.99	-	0.095	0.191	-	0.006	11.03
10th	3.01	-	0.105	0.212	-	0.006	10.99
11th	3.01	0.004	0.035	0.066	0.005	0.003	10.94
12th	2.99	0.003	0.025	0.066	0.006	0.002	10.86

13th	3.02	0.004	0.034	0.084	0.005	0.005	10.87
14th	2.99	0.003	0.030	0.091	0.005	0.003	10.70
15th	2.99	0.002	0.030	0.089	0.005	0.004	10.67
16th	2.99	0.002	0.044	0.088	0.005	0.003	10.46
17th	2.99	0.004	0.052	0.087	0.006	0.004	10.48
18th	2.99	0.003	0.066	0.090	0.007	0.006	10.35
19th	3.00	0.004	0.065	0.087	0.009	0.005	10.38
20th	2.99	0.003	0.059	0.090	0.012	0.007	10.23

Note 1."-"sign indicates the concentration of the element is undetectable.
Note 2. Two cured cement structure samples were crushed and tested. The results were recorded. The results shown on the table were the mean of two test results.

(4) TCLP:

The samples were tested with TCLP (EPA No. 28002: NIEA R201.11C) to determine its toxic contents.

Table 5. The TCLP test result after solidification

The time of solidification	Zn (mg/l)	Pb (mg/l)	Cr (mg/l)	Cu (mg/l)	Cd (mg/l)	As (mg/l)	Org-Hg (mg/l)	T-Hg (mg/l)
Reaction Ash	6.00	92.13	0.33	1.32	0.14	<0.05	0.030	0.358
4hr	0.11	1.81	0.06	0.06	0.06	-	-	-
1 day	0.10	1.54	0.02	0.06	0.06	-	-	-
3 day	0.09	1.45	0.02	0.06	0.06	-	-	-
7 day	0.09	1.42	0.04	0.06	0.07	-	-	-
14 day	0.02	1.45	0.22	0.04	0.06	-	-	-
28 day	0.04	0.47	0.12	0.04	0.06	<0.05	ND	0.00064
EPA regular	--	5.00	5.00	15.00	1.00	5.00	ND	0.2

Note: 1. 5Kg of reaction ash samples were selected randomly for each test. The test was being duplicated to increase its reliability (the test results are the mean of two tests). The results shown are the mean of two tests.
2. The crushed brick samples were tested twice with TCLP and the results recorded were the mean of two tests.

According to table 4, the amount of leached Pb from solidized blocks was 92.13 ppm before solidification; 1.81 ppm after 4-hour-solidification (the value decreased by 94%); 0.47 ppm after 28-day-solidification. The value of Pb detected has dropped significantly. It shows that the heavy metal will not be leached into natural environment and cause chemical pollution.

B. Physical Properties

The absorption and specific gravity of coarse aggregate were tested by ASTM C127 to determine the density of the aggregate. Its particle strength was determined by CNS 1232 A3045, ASTM C469 and Test for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine (CNS 490 A 3009) in order to test the potential applicability of the aggregate.

(1) LA test

Two types of aggregate (concretization aggregate and pelletization aggregate) were tested for their Test for Resistance to Abrasion of Small Size Coarse Aggregate. 5 Kg of sample was collected and tested with the Los Angeles Machine and the results were recorded as followed:

Table 6. Test for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles machine.

Sample	Sieve analysis	The Resistance to Abrasion (%)
Concretization aggregate	B type	45.2
Pelletization aggregate	C type	27.9

Note: Sieve analysis: Size of B type sieve : 19~9.5mm ; Size of C type sieve : 9.5~4.75mm

(2) The test for Absorption rate and Specific Gravity (ASTM C127)

Table 7. The test for Absorption rate and Specific Gravity.

Sample	Absorption rate (%)	Specific Gravity
Concretization aggregate	17.8	1.8
pelletization aggregate	9.0	2.0

Note: the absorption rate and specific gravity were tested twice. The results recorded were the mean of two tests.

From Table 9, the Test for Resistance to Abrasion of Small Size Coarse Aggregate varies due to the different processes of formation. The concretization aggregate is 45.2% and the pelletization aggregate is 27.9%. This result has shown that pelletization aggregate has higher density. While concretizating large amount of water was added to the reaction ash to shorten the concretization process, but this also weakened the particle strength of concretization aggregate.

From results shown on table 10, the absorption rate of pelletization aggregate is lower than the absorption rate of concretization aggregate. The specific gravity of pelletization aggregate is higher than concretization aggregate. The results proved that the density of pelletization aggregate is greater than concretization aggregate.

(3) The test for particle strength

The test results for particle strength of concretization and pelletization aggregate were shown on table 11:

Table 8. The test for particle strength. Unit : kgf/cm^2

Formula \ curing		7days	14days	28 days
Concretization aggregate	1:1:1	50	52	89
Pelletization aggregate	1:1:1 (Particle size 13.8mm)	-	-	48

Note: The tests for particle strength were tested twice. The results recorded were the mean of two tests.

(4) Compressive strength test

The test for compressive strength of recycle bricks is conducted based on CNS 1232 A3045 and ASTM C469 standards.

Table 9. The test for compressive strength of recycle bricks. unit : kgf/cm^2

Formula \ Curing		7days	14days	28 days
Concretization aggregate	1:1:1	50	55	108
	1:2:2	-	-	90
Pelletization aggregate	1:1:1	65	69	142
	1:2:2	-	-	126

Note: the absorption rate and specific gravity were tested twice. The results recorded were the mean of two tests.

The tests for compressive strength of two types of recycle bricks were determined as well. After 28-day-curing process, the strength of bricks made from pelletization aggregate is 142kgf/cm^2 and the strength of bricks made from concretization aggregate is 108kgf/cm^2.

4. Discussion and Applications

The comparison of concretization and pelletization aggregate (see table 14)

Table 10. The comparison between pelletization and concretization aggregate.

Technique	Strength	Weakness
Concretization aggregate	1.Stable. 3.cheaper.	1 The strength has not achieved the architectural standards. (<150 kg/cm^2) 2.The heavy metal content might be leached out in a long term.
Pelletization Aggregate	table and the heavy metal will not be leached out.	Not as strong as natural gravel.

This study has investigated the applicability of recycling reaction ash. One of the options is to make recycle bricks from the reaction ash by concretization and pelletization. Both types of recycle bricks cannot be used, as structure walls due to the strength of both are less than 150kg/ cm^2. (Standard qualified by Taiwan Architecture Bureau). It is safe to use the recycle bricks to substitute the non-structural walls. The leaching of heavy metal is under limit and it will not cause further environment hazards. However, the long-term observation is recommended, for it needs further observation of three to five years to confirm its general stability and safety before it should be made in public circulation.

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