Effects of waste utilization on reduction of natural resource consumption, landfilling and greenhouse gas emission in the cement production process in Japan

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Introduction

-The construction of new landfill sites is considered to be almost impossible in Japan because of growing public awareness of environmental conservation.
-"The second fundamental plan for establishing a sound material-cycle society," which was approved by the Cabinet in 2008, set quantitative targets for three indicators:
resource productivity, cyclical use rate and final disposal amount.
-Japan's cement industry greatly contributed to waste minimization in FY2006 by utilizing approximately **30.9 million tons** of waste generated from various basic industrial sources such as the iron and steel industry, power industry, automobile industry, etc.

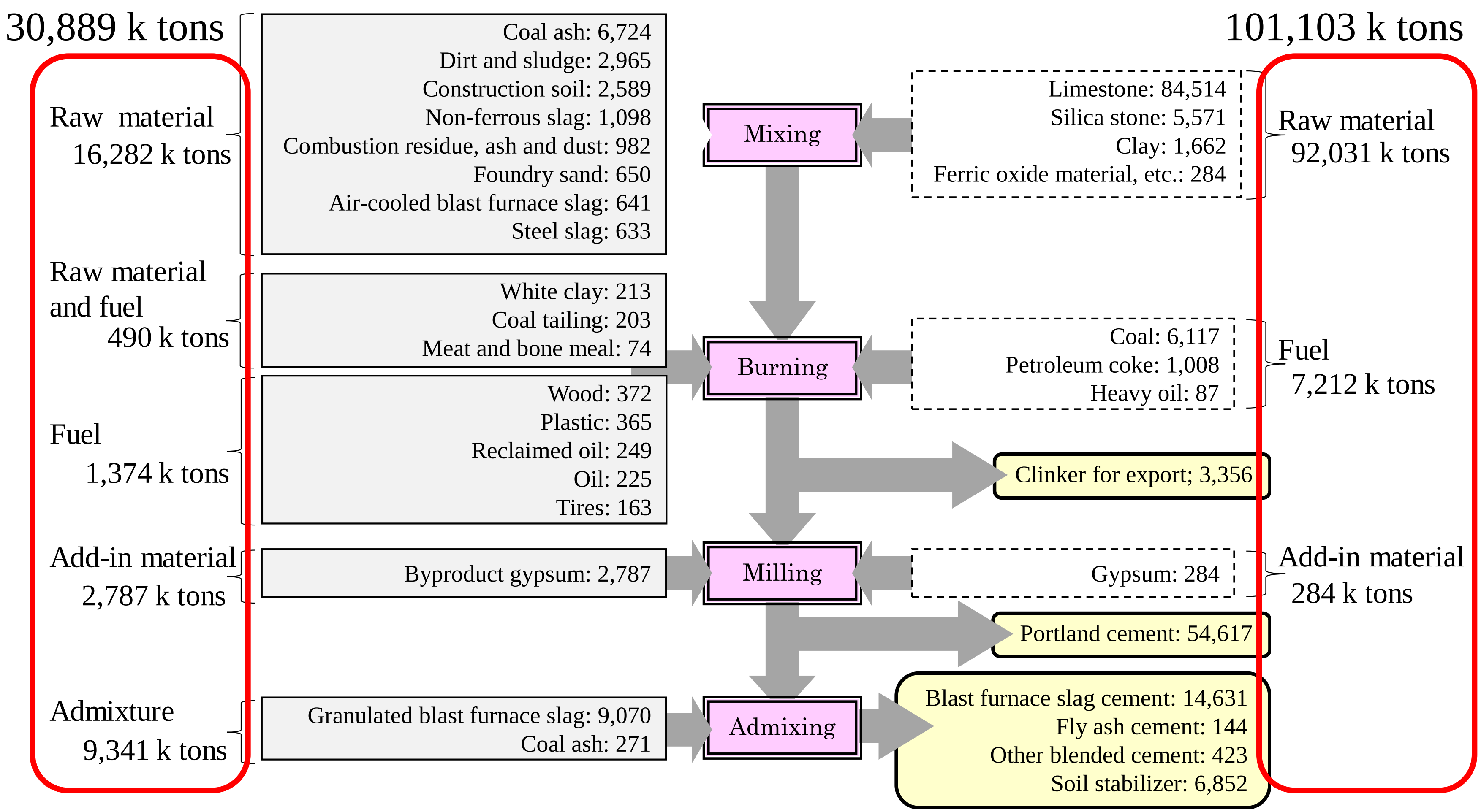
Objectives

-to estimate the effects of waste utilization on reduction of natural resource consumption, landfilling and greenhouse gas emission in the cement production process in Japan

-to estimate variations in resource productivity, cyclical use rate and final disposal amount between with and without waste utilization for cement production

Note that the effects of heavy metals were not taken into consideration in this study.

Japan's cement industry



<u>423 kg-waste/ton-cement product</u>

Fig. 1. Inventory of natural resources, waste and products in Japan's cement industry in FY2006 (k ton).

Similarity between natural resources and waste utilized

Table 1
Chemical composition of raw materials for clinker production

Classification	Substitution	Moisture (%)	Dried basis (oxide equivalent %)				
			Ignition loss	CaO	SiO_2	Al_2O_3	Fe_2O_3
Natural resources	Limestone	2.6	42.2	52.8	2.4	0.6	0.4
	Silica stone	7.3	2.1	0.8	85.5	6.0	2.5
	Clay	13.1	5.4	2.0	66.0	14.8	5.2
	Ferric oxide material	5.0	5.0	0.0	0.0	0.0	65.0
Waste	Coal ash	0.1	1.5	5.2	57.3	25.4	9.5
	Dirt and sludge	54.2	10.0	17.5	25.0	35.0	7.5
	Construction soil	20.0	5.4	2.5	62.5	20.0	6.5
	Combustion residue, ash and dust	19.0	12.4	25.0	25.0	15.0	5.0
	Non-ferrous slag	0.5	4.1	2.7	32.5	4.1	48.2
	Foundry sand	5.0	6.0	2.5	65.0	10.0	7.5
	Air-cooled blast furnace slag	6.8	1.7	42.0	33.8	14.4	0.3
	Steel slag	6.8	1.7	44.3	13.8	1.5	17.5
	White clay	5.0	40.0	1.3	41.9	9.4	3.3
	Coal tailing	10.0	5.0	12.5	52.5	20.0	6.5
	Meat and bone meal	5.0	90.6	9.4	0.0	0.0	0.0

Which waste replaces which natural resources in the clinker production process?

Similarity between natural resources and waste utilized

The result of hierarchical cluster analysis

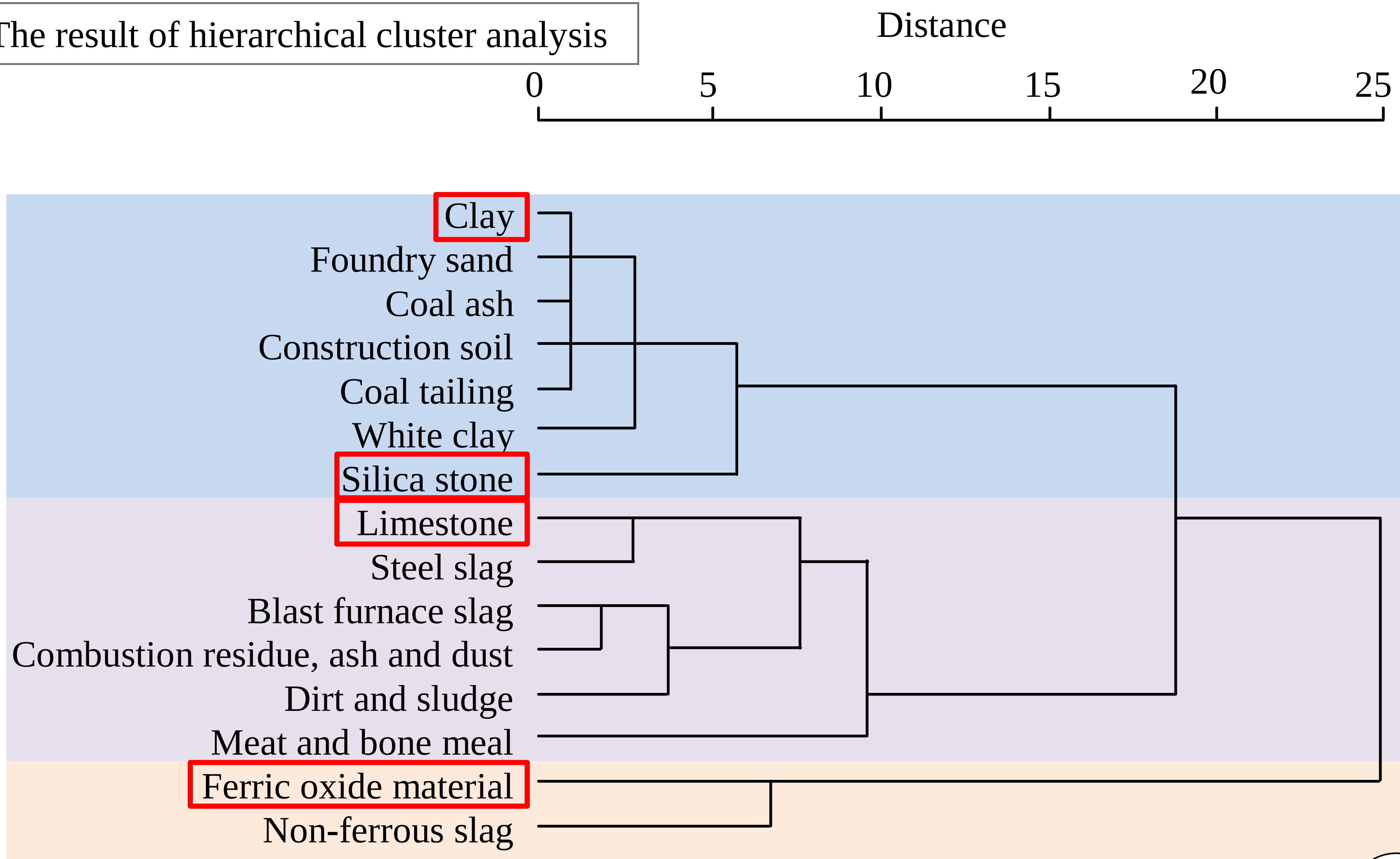


Fig. 2. Dendrogram showing the similarity in chemical composition between natural resources and waste.

Substitution rate of waste for natural resources

Substitution rate: Substituted natural resources (ton) by one ton of waste

Table 2
Substitution rate of waste for natural resources in clinker production process

Substitution	Material	Substitution rate (%)
Limestone	Steel slag	80.3
	Air-cooled blast furnace slag	76.1
	Combustion residue, ash and dust	39.4
	Meat and bone meal	17.4
	Dirt and sludge	15.6
Silica stone	Foundry sand	32.7
	Coal ash	30.3
	Construction soil	26.5
	Coal tailing	25.0
	White clay	21.1
Clay	Foundry sand	62.5
	Coal ash	57.9
	Construction soil	50.6
	Coal tailing	47.8
	White clay	40.3
Ferric oxide material	Non-ferrous slag	77.7

Effects on reduction of natural resource consumption

Table 3
Amount of substitution for natural resources as raw material by waste utilization

Process	Substitution	Amount (k ton, wet basis)
Clinker production	Limestone	1,859
	Silica stone	3,031
	Clay	5,793
	Ferric oxide material	853
Milling	Gypsum	3,131
Admixing	Limestone	11,176
	Silica stone	31
	Clay	2,976
	Ferric oxide material	181
Total		29,029

Without waste utilization, natural resource consumption would have increase by 29 million tons

- 24%

Effects on reduction of natural resource consumption

Table 4
Amount of substitution for natural resources as fuel by waste utilization

Process	Substitution	Calorific value (TJ)
Clinker production	Coal	39,432
	Petroleum coke	7,219
	Heavy oil	955
Admixing	Coal	20,963
	Petroleum coke	3,407
	Heavy oil	332
Total		72,307

- 27%

Effects on reduction of landfilling

Table 5
Waste disposal reduction by waste utilization

Waste	Reduction (k ton, wet basis)	Disposal rate (%)
Construction soil[*1]	642	24.8
Coal ash	549	7.9
Foundry sand	433	66.7
Non-ferrous slag	210	19.2
Coal tailing[*1]	203	100.0
Combustion residue, ash and dust	193	19.6
Dirt and sludge	150	5.1
White clay[*1]	128	60.0
Plastic	125	34.4
Wood	30	8.0
Meat and bone meal[*2]	23	30.7
Steel slag	19	3.1
Reclaimed oil	9	3.5
Oil	8	3.5
Tires	2	1.2
Blast furnace slag	0	0.0
Byproduct gypsum	0	0.0
Total	2,725	

Effects on reduction of greenhouse gas emission

Table 6
Greenhouse gas emission and reduction in the cement industry

Source	Emission (k ton-CO_2)*1	Reduction (k ton-CO_2)*2
Raw material	32,470	5,551
Fuel	21,840	3,720
Total	54,310	9,271

- 15%

Resource productivity, cyclical use rate and final disposal amount

$$\textbf{Resource productivity} = \frac{\text{GDP}}{\text{Natural resource consumption}}$$

$$\textbf{Cyclical use rate} = \frac{\text{The amount of cyclical use}}{\text{The amount of cyclical use} + \text{Natural resource consumption}} *100$$

Table 7

Variations in resource productivity, cyclical use rate and final disposal amount between with and without waste utilization for cement production in FY2006 compared to the targets for FY2015

Indicator	Unit	Target in 2015*1	With waste utilization in 2006*2		Without waste utilization in 2006
Resource productivity	10^3 JPY/ton	420	348	**+ 7,000 JPY**	341
Cyclical use rate	%	14–15	12.5	**+ 0.5%**	12.0
Final disposal amount	10^6 ton	23.0	28.6	**- 2.7 10^6ton**	31.3

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Concentrations of trace elements in Portland cement

Table 8

Utilized waste per unit weight of cement and concentration of trace elements in Portland cement

Year	Waste (kg/ton-cement)	Concentration (mg/kg)[*1]							
		T-Cr	Zn	Pb	Cu	As	Se	Cd	Hg
1994	253	86	563	145	125	15	–	2.4	0.01
1999	311	86	467	78	126	13	0.1	1.7	0.007
2000	332	92	427	78	116	15	0.8	2.2	0.008
2001	355	83	460	82	136	13	1.1	1.8	0.013
2002	361	80	432	68	129	12	1.2	1.2	0.011
2003	375	74	492	62	165	13	0.9	1.6	0.015
2004	401	76	493	81	144	14	1.2	1.3	0.01
2005	400	79	495	84	151	14	1.1	<3.0	0.01
Soil concentration standard[*2]		250	–	150	–	50	150	150	15

*1 Taiheiyo Cement Corporation (2009).

*2 Designated in the Soil Contamination Countermeasures Law

Calculation of substitution rate

The substitution rate for limestone

The proportion of CaO in waste type *i* (wet basis %)

$$R_L = \frac{W_{i\,CaO}}{L_{CaO}} * 100$$

The substitution rate for silica stone

The proportion of SiO_2 in waste type *i* (wet basis %)

The proportion of SiO_2 in clay (wet basis %)

$$R_S = \frac{W_{i\,SiO_2}}{S_{SiO_2}} * \frac{C_{SiO_2}}{(S_{SiO_2} + C_{SiO_2})} * 100$$

The proportion of SiO_2 in silica stone (wet basis %)

The substitution rate for clay

$$R_C = \frac{W_{i\,SiO_2}}{C_{SiO_2}} * \frac{S_{SiO_2}}{(S_{SiO_2} + C_{SiO_2})} * 100$$

The substitution rate for ferric oxide material

The proportion of Fe_2O_3 in waste type *i* (wet basis %)

$$R_F = \frac{W_{i\,Fe_2O_3}}{F_{Fe_2O_3}} * 100$$

The proportion of Fe_2O_3 in ferric oxide material (wet basis %)