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Properties of Ecocement Manufactured Using Large Amounts of Municipal Waste Incinerator Ash – A Contribution of Cement Industry in Establishing a Sustainable and Recycling-Based Society –

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ABSTRACT

This paper describes the present situation of waste and by-products utilization in cement manufacturing in Japan, introduces Ecocement which is a new cement using municipal waste incinerator ash from household activities as the primary raw material, and discusses the contribution expected of the cement industry in establishing a resource recycling-based society in this country.

Keywords. Cement, Ecocement, Waste, By-products, Resource recycling-based society

INTRODUCTION

Cement production in Japan peaked at 99.27 million tons in 1996 and then has been decreasing to reach a level of 1970s, 56.05 million tons, in 2010 (Japan Cement Association, 2012). This is proof of the maturity of the Japanese cement industry which has been experienced in the advanced countries in Europe. However, as no complete replacement for cement is yet available as of the beginning of the 21st century, the cement industry is expected to continue providing reliable supply of the basic construction material.

There have been many dramatic changes in circumstances surrounding cement during the period of decline in production. Cement and concrete with higher performance or higher functionality have been developed, cement-related standards have been standardized internationally, and significant advance has been made in the development of analytical techniques. The other important change is the use of industrial waste and by-products in cement manufacturing which has been increasing with the increase of environmental concerns.

This paper describes the present situation of waste and by-products utilization in cement manufacturing in Japan, introduces Ecocement which is a new cement using municipal waste incinerator ash from household activities as the primary raw material, and discusses the contribution expected of the cement industry in establishing a resource recycling-based society in this country.

UTILIZATION OF WASTE AND BY-PRODUCTS BY THE CEMENT INDUSTRY IN JAPAN

The original primary purpose of using waste and by-products in the cement industry, which started in 1970s in Japan, was to reduce raw material and fuel costs. A wide variety of waste and by-products are now used in large quantities, with the total amount used in 2010 amounting to 25.42 million tons as shown in Table 1 (Hirao,2006, and Japan Cement Association Homepage,2012). This figure is equivalent to 469 kg per ton of cement, increasing by about 220 kg from the level in 1990.

There are several reasons why the use of such large quantities of waste and by-products is possible in cement manufacturing: for instance, production of cement itself is large in quantity; waste and by-products generally contain major constituents of cement; unwanted contents can be decomposed or volatilized during high-temperature calcination; and the form of cement allows for ready verification of the safety of the recycled contents or the exhaust gases generated from the processes (Hirao,2006). However, waste and by-products may contain minor or trace elements which can affect quality of cement or the environment. Contents and possible impact of minor and trace elements as well as those of major constituents are carefully investigated in actual application to determine the adequacy for use, requirements for use and proper control procedures. The waste and by-products used in cement manufacturing can be classified into the following categories by the type or usage: alternative raw materials; alternative fuels; additives; and gypsum. The following sections summarize each of these categories.

Alternative Raw Materials. Waste and by-products used as raw materials of cement include steel making slag and coal ash excluding fly ash. They are used as alternative clay. The use of coal ash is increasing in recent years, with up to about 60% of the total amount generated being used for cement. New alternative raw materials also include surplus soil. Cinder and some other types of waste contain high heat quantity in addition to the major constituents of cement.

Table 1. Utilization of waste and by-products in the cement industry in Japan (in thousand tons)

Types of Waste and by-products	Usages	1990	1995	2000	2005	2010
Blast furnace slag	Raw material, Additive	13,007	12,486	12,162	9,214	7,345
Coal ash	Raw material, Additive	2,021	3,103	5,145	7,185	6,443
Dirt, Sludge	Raw material	—	905	1,906	2,649	2,514
Gypsum by-product	Raw material, Additive	2,300	2,502	2,643	2,572	1,974
Surplus soil	Raw material	—	—	—	2,097	1,931
Nonferrous slag	Raw material	1,233	1,396	1,500	1,318	654
Cinder, Soot and dust	Raw material, Fuel	—	487	734	1,189	1,261
Molding sand	Raw material	—	399	477	601	478
Steel making slag	Raw material	—	1,181	795	467	400
Waste wood	Raw material, Fuel	—	—	2	340	564
Coal sludge	Raw material, Fuel	1,600	1,666	675	280	0
Waste plastics	Fuel	—	—	102	302	413
Reclaimed oil	Fuel	—	126	239	228	195
Waste oil	Fuel	141	107	120	219	269
Waste tire	Raw material, Fuel	101	266	323	194	87
Waste white clay	Raw material, Fuel	41	94	106	173	236
Meat and bone meal	Raw material, Fuel	—	—	0	85	61
Others	—	1360	379	431	468	591
Total		21,763	25,097	27,359	29,593	25,415
Cement production		86,849	97,496	82,373	73,931	56,050
Amount of waste and by-products per ton of cement production (kg)		251	257	332	400	469

Alternative Fuels. There was a rapid shift in fuel from petrol to coal in cement manufacturing in Japan after the second oil crisis in 1978. The use of waste tires as an alternative fuel also started around 1980. Up to 10% of total waste tires generated are used for cement at present. Recent alternative fuels also include waste plastics. Debris from fuel combustion such as coal ash, in case of coal, and wires, in case of waste tires, can be recycled as raw materials in cement manufacturing, without generating additional by-products. This makes the use of waste in cement manufacturing remarkably advantageous. Moreover, the use of waste as fuels results in reduction in carbon dioxide emissions from incineration and reduction in consumption of coal and other natural fuels, thereby making a contribution to the control of carbon dioxide emissions.

Additives and Gypsum. Gypsum which is added during the finishing process of the cement clinker manufacturing is essential to the control of cement setting time. Although gypsum is produced in nature, gypsum by-products from other industries have been used since 1950s in Japan due to its limited natural supply.

Blast furnace slag, fly ash and other additives which are also added during the finishing process are major alternative raw materials in blended cement. The use of blast furnace slag likely started during the Taisho period (1912 to 1926), while the use of fly ash started around 1951 (Iizuka, 1992). Blast furnace slag cement follows normal Portland cement in the amount of production, accounting for 24.4% of the total cement production in 2010. On the other hand, fly ash cement accounts for only less than 1% of the total cement production. The use of additives is expected to be an effective measure to reduce the environmental impact, and active research is being conducted about blended cement containing larger amounts of additives for the purpose of establishing lower carbon technologies with minimal environmental impact (Wachi, 2012).

Non-industrial Waste Generated by Household Activities. Increasing amounts of municipal waste, sewage sludge and other non-industrial wastes generated by household activities are used as cement raw materials as shown in Table 2 (Taiheiyo Cement Corporation, 2007,2008,2009,2010,2011). Since many municipal governments are faced with difficulties in disposal of these wastes, their use in the cement manufacturing will continue to increase as one of the effective disposal measures.

The cement industry is closely related with both industrial and household activities as described above, having an indispensable role in establishing a recycling-based society. Its public importance is becoming greater as they help in disposal of disaster debris and waste from the Great East Japan Earthquake (the 2011 off the Pacific Coast of Tohoku Earthquake) which occurred in March 2011.

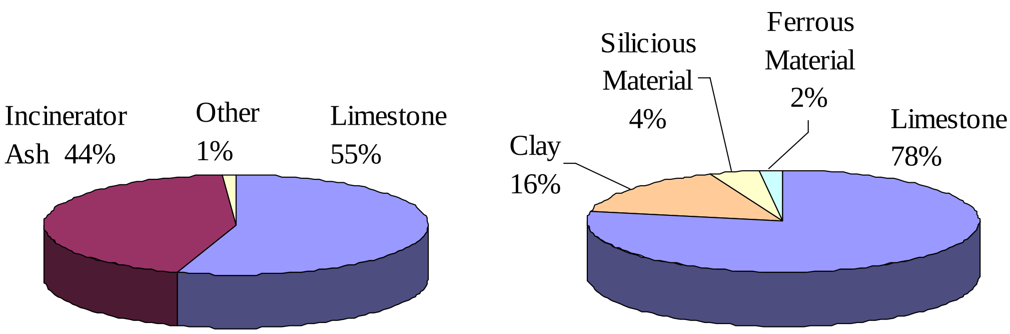
Table 2. Changes in the amount of municipal waste, sewage sludge and other non-industrial waste received by Taiheiyo Cement Corporation (in thousand tons)

Waste types	2005	2006	2007	2008	2009	2010
Municipal waste incinerator ash	59	61	70	77	76	86
Sewage sludge, Sewage sludge incinerator ash	247	318	351	353	333	296
Other municipal waste	16	16	16	16	16	16
Total	322	395	437	446	425	398

ECOCEMENT — CEMENT USING MUNICIPAL WASTE INCINERATOR ASH AS THE PRIMARY RAW MATERIAL

Features of Ecocement. Ecocement is a new cement which uses incineration ash of non-industrial municipal waste as the primary raw material. The conventional cement materials are replaced with waste and by-products in Ecocement at the maximum possible ratios as shown in Figure 1. The amount of waste and by-products per ton of cement production was 469 kg in 2010 as shown in Table 1. However, with gypsum by-product and blast furnace slag for blended cement excluded, waste and by-products used in the same year was 16.096 million tons, or 287 kg per ton of cement production. In contrast to this, Ecocement uses municipal waste incinerator ash at up to more than 600 kg per ton of cement.

Municipal waste incinerator ash contains high levels of chloride ions which are removed by volatilization during the manufacturing process of Ecocement. This process also removes heavy metals contained in the incineration ash. The heavy metals separated from the chloride-containing dust are collected and recycled at refineries, with no additional waste generated from the recycling process.



Blend Ratio of Raw Materials in Ecocement

Blend Ratio of Raw Materials in Normal Portland Cement (In Case of Manufacturing from Natural Raw Materials)

Figure 1. Ratio of Raw Materials in Ecocement and Normal Portland Cement

Properties of Ecocement. Tables 3 and 4 show chemical and physical characteristics of Ecocement. Ecocement is similar to normal Portland cement in properties and therefore has a wide range of applications including ready-mixed cement and various concrete products (Tanaka, 2003). Recycled waste tends to contain higher levels of Al_2O_3 and chloride ions as compared to normal Portland cement. Use of larger quantities of recycled waste will inevitably result in increased contents of these substances in cement. With more waste utilized, normal Portland cement will have a closer composition to that of Ecocement in future.

Table 3. Chemical and Compound Composition of Cement

Cement Types*	Chemical Composition (%)								
	Ig.loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	R_2O	Cl
E	1.1	17.8	7.2	4.1	61.1	1.8	3.9	0.3	0.054
N	2.4	21.5	4.9	2.8	64.6	1.2	2.0	0.6	0.008
B	0.5	25.4	8.2	1.9	55.3	3.4	1.7	0.5	0.00

Cement Types*	Compound Composition (%)			
	C_3S	C_2S	C_3A	C_4AF
E	49	12	14	13
N	57	19	8	8
B	—	—	—	—

*E: Ecocement; N: Normal Portland Cement; B: Blast Furnace Slag Cement

Table 4. Physical Properties of Cement

Cement types*	Density (g/cm^3)	Fineness (cm^2/g)	Setting			Compressive Strength (MPa)		
			Amount of water (%)	Initial (h:m)	Final (h:m)	3day	7day	28day
E	3.19	4130	31.2	2:40	4:10	28.8	36.3	51.2
N	3.15	3490	26.9	2:20	3:10	28.2	43.4	59.0
B	3.04	4120	28.9	2:40	4:15	20.8	34.4	59.8

*E: Ecocement; N: Normal Portland Cement; B: Blast Furnace Slag Cement

Standards Related to Ecocement. There are three Japanese Industrial Standards (JIS) related to Ecocement: JIS R 5214 Ecocement; JIS A 5308 Ready-mixed cement; and JIS A 5364 Precast concrete products -- General rules of materials and product methods. Standard design and construction methods for concrete using Ecocement are presented by the Public Works Research Institute and the Architectural Institute of Japan.

Ecocement Plants. The first plant of Ecocement in the world started its operation in 2001 in Ichihara City, Chiba Prefecture, Japan. This plant is capable of accepting municipal waste incinerator ash from about 1.5 million residents and producing about 110,000 tons of Ecocement a year. The other plant located in Hinode Town, Nishitama County, Tokyo started its operation in 2006, with capacities of accepting municipal waste incinerator ash from about 3.9 million residents and producing about 130,000 tons of normal Ecocement a year (Figure 2). Ecocement presents a possible model of future cement manufacturing as a new form of business established for suburban locations with a small production capacity less than one-tenth the conventional size.

Figure 2. Ecocement Plant in Tokyo

Promotion of Use of Ecocement Concrete by Local Governments. Local governments with Ecocement production facilities actively promote use of Ecocement as a recycling material product in their campaign for “local production, local consumption”. Chiba and Tokyo prefectural governments where Ecocement plants are placed have a system to designate concrete products using Ecocement as “Eco-Friendly Goods” and encourage preferential use of these products. Products using Ecocement bear a certification mark as shown in Figure 3, so that anyone can easily recognize that Eco-Friendly Goods containing Ecocement are used.

Ecocement itself was certified as an Eco Mark product by the Japan Environment Association in 2002, and it was listed in the designated procurement items under the Law Concerning the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities (the Law on Promoting Green Purchasing) in 2004.

Figure 3. Certification marks for concrete products using Ecocement by Tokyo Tama Wide-Area Recycling Association

CONCLUSION

This paper described utilization of waste and by-products in cement manufacturing and discussed a contribution of the cement industry in establishing a resource recycling-based society in Japan. The use of industrial waste which originally started as a measure of raw material and fuel cost reduction has evolved to now include recycling of municipal and non-industrial waste. This is highly regarded as a new contribution of the cement industry to the society due to the growing concerns about environmental issues and the more limited availability of landfill sites. The excellent energy use efficiency achieved by the Japanese cement industry through development and introduction of advanced equipment and technologies is at the highest level in the world. In addition, enhanced diversity of cement that meets the development of higher performance or higher functionality concrete leads to increased applications of concrete. Various phenomena are investigated using advanced analytical techniques to support further advancement of cement and concrete technologies.

The cement industry in Japan will play a key role in the establishment of a resource recycling-based society through development of advanced technologies for the utilization of waste and by-products, while fulfilling the mission as a fundamental industry to supply the cement which is indispensable for the construction and management of infrastructures.

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