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Modern Trends and Developments of New Cement for Sustainability of Construction Materials: A Review

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Abstract: ***This research describes an elaborative discussion on the modern trends and developments of new cements for sustainability of construction materials. The new cements manufacturing is provided a fundamental understanding of the characteristics of new cements for sustainability of construction materials in terms of three parts: Eco-cement; Steel slag concrete; and Municipal slag concrete. Eco-cement with saving of natural resources by the utilization of wastes and saving energy in cements manufacturing. Steel slag concrete whose binder is steel slag, which includes steel slag with fly ash, steel slag hydrated matrix and steelmaking slag carbonated matrix. Municipal slag concrete whose binder is a ground granulated melt-solidified slag derived municipal solid waste or sewage sludge. This research accordingly attempts to focus on the modern trends and developments of new cements for sustainability of construction materials.***

Keywords: Eco-cement, steel slag concrete, municipal slag concrete, sustainability, construction materials.

1. Introduction

As used in everyday speech and has become one of the modern buzz words, sustain means to support or to keep a process going, and the goal of sustainability is that life can be sustained for the foreseeable future. There are three components of sustainability: environment, economy, and society. To meet its goal, sustainable development must provide that these three components remain balanced. Sustainable construction material is an initiated imperative to improve the social, economic and environmental performance that meets the need of the present without compromising the needs of future generations to meet their own needs.

The humankind causes the environmental damage of global scale through its activity, and it stands at the crossroad of whether it can sustain this society. Generation of greenhouse effect gas with industrial activity and consumption of large resources have caused the environmental damage. Concrete is an important material as the construction material of infrastructures, which help the human activities as well as steel reinforcement. The mass use of concrete causes environmental damage as the cement which is the binding material of concrete discharges much carbon dioxide with the manufacturing and it consumes a great deal of natural resources as aggregate. Decrease of discharge of carbon dioxide, which is a greenhouse effect gas, and effective utilization of some resources are important for a realization of the sustainable society. The above two points are related mutually, and both are realized by realizing one. This research introduces the activity for realizing the sustainable construction materials in new cement manufacturing and new alternative materials of Portland cement of concrete construction.

To meet long-term growth in demand for the challenges of new cement for sustainable construction materials, there are numerous investigating a range of future manufacturing options of new cement [1,2]. These include a variety of upgrade alternatives for its current cement manufacturing. The research describes the modern trends and developments of new cements for sustainability of construction materials. The new cements manufacturing is provided a fundamental understanding of the characteristics of new cements for sustainability of construction materials in terms of three parts: Eco-cement; Steel slag concrete; and Municipal slag concrete. Eco-cement with saving of natural resources by the utilization of wastes and saving energy in cements manufacturing. Steel slag concrete whose binder is steel slag, which includes steel slag with fly ash, steel slag hydrated matrix and steelmaking slag carbonated matrix. Municipal slag concrete whose binder is a ground granulated melt-solidified slag derived municipal solid waste or sewage sludge [3,4].

Therefore, the intending to be as brief as is consistent with the goals of the discussion is divided into three parts: Eco-cement; Steel slag concrete; and Municipal slag concrete.

2. Eco-Cement

2.1 Eco-cement resources system

The cement industry has been accepting a various waste as fuel for manufacturing cement. Many problems about the reclaimed land board by this waste take place. It tried the suggestion of suitable reclaimed method of the waste from the viewpoint of construction engineering and sustainable society utilization, an attempt has been made in recent years to produce a composition which is suitable as a raw material of portland cement. But, most of ashes resulting from incinerated municipal wastes contain chlorine and couldn't use as raw materials of portland cement.

At present, most of the final disposal places are filled up by the waste such as incinerated ashes and it is very difficult to receive the agreement of the inhabitant for making the final disposal place in Japan. In Japan, the cement industry developed new systems to utilize municipal wastes as well as industrial wastes as raw materials of cement or energy sources in manufacturing cement. Figure 1 shows the concept of recycling resources system in cement industry for sustainable society.

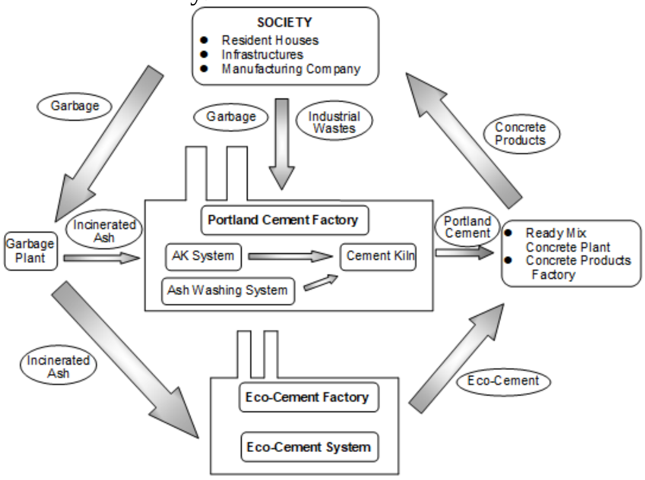

Figure 1: Recycling resources system in cement industry

2.2 Utilization of incinerated ash

Eco-cement is the cement whose main raw material is the incinerated ash. The eco-cement was certified as JIS (Japanese Industrial Standards). The JIS regulates to use dried incinerated ash over 500kg on the manufacturing 1 ton of cement. The toxic substances which are included in the incinerated ash are removed following methods. Dioxins are decomposed by the calcinations process. Heavy metals react with chlorine ion and they become the heavy metal chlorides in the kiln. These chlorides are volatilized under calcinations as their boiling points are low and are caught while manufacturing. Simultaneously, the reduction of the chlorine ion is also decreased by this method.

Two types of eco-cement, ordinary eco-cement and rapid hardening eco-cement are regulated. The upper limit of the chlorine ions of ordinary eco-cement is 0.1%, and it is bigger than the upper limit 0.035% of the ordinary portland cement. However, results of the chloride quantity of eco-cement are around 0.05%.

The ordinary eco-cement is used for non-reinforced and reinforced concrete for general concrete structures. The utilization to high strength concrete and pre-stressed concrete is excluded. The rapid hardening eco-cement hardens faster than the high early strength portland cement. In the manufacturing of the rapid hardening eco-cement, the chlorine ion is changed to constituent minerals in cement which shows hydraulic property. Quantity of chlorine ion in the rapid hardening cement is regulated within 0.5-1.5% and is used for non-reinforced concrete. There are two factories are working in Japan. The use of eco-cement is now expanding as the material for ready mixed concrete and concrete products.

2.3 Utilization of wastes and by-products

In Japan, the utilization of wastes and by-products are developed in the cement manufacturing for saving of natural resources and energy. Wastes or by products (of about 430kg) are used to produce 1 ton cement. The quantity is about 240kg, when it is limited usage of waste. In the cement manufacturing, the following wastes or by products are used as raw material: coal ash, incinerated ash, sewage sludge, casting sand, waste tire, waste plastic and blast furnace slag. The wastes or by products used in the cement manufacturing, contain CaO, SiO2, Fe2O3 and Al2O3, which are major components of the cement. The usage percentages of those wastes or by products, as cement raw material and admixtures in concrete are 33% of the blast furnace slag, 62% of the coal ash and 18% of the waste tire.

2.4 Incinerated ashes washing system

The eco-cement factory needs a large amount of incinerated ash. Therefore, it is difficult to build the eco-cement factory in a local area and the use of eco-cement is limited as the cement contain larger amount of chlorine. A cement company in Japan developed a system for using incinerated ashes of municipal wastes as a raw material of portland cement by removing the chloride by water washing.

2.5 Eco-services of applied kiln system

Various eco-services have been recently introduced in Japan as a proactive approach to create a sustainable society. These eco-services include a wide range of eco-service has its own unique characteristics. It is necessary to systematically classify these eco-services into different categories to understand the development trend as well as to promote these eco-services with regard to sustainable development. In addition, overall environmental impacts and economic benefits of these eco-services need to be quantitatively evaluated using a life cycle approach to ensure the real benefits of eco-service. Municipal waste treatment systems with two different scenarios of landfill and recycling in cement production were used.

These systems accept house hold garbage or general wastes and put it into a resource recovery kiln, and biodegradation reaction called aerobic fermentation is carried out with air without using burners. The gas which arises under decomposition is used as the thermal energy for the cement firing and is perfectly deodorized. This system can omit the construction of cleaning center and eternal disposal site in the neighborhood area of the cement company.

3. Steel Slag Concrete

3.1 Steel slag concrete whose binder is steel slag

A crude steel output in Japan is around one hundred million tons. About 39 million tons of the iron and steel slag are produced through it. The blast furnace slag is discharged with the production of pig iron. The output of the blast furnace slag in Japan is the about 25 million tons every year. The blast furnace slag is used for cement raw material, concrete admixture, concrete aggregate and sub-bases, etc., as the chemical composition and properties of the slag are uniform, and almost 100% of the slag is used effectively.

In Japan, the steelmaking slag which is made by converter, discharges the annual about 14million tons. The steelmaking slag is discharged with the steel production in the converter. The output of the steelmaking slag in Japan is the about 25 million tons every year. The steelmaking slag forms calcium hydroxide by reacting free-CaO which is a component in the slag and the water.

Therefore, the steelmaking slag is used after long term aging in the field or the short term aging using steam. Since the steelmaking slag expands in concrete even after the aging, it is not used as an aggregate.

The coal ash generated with coal fired power generation is discharges about 10 million tons every year, in Japan. The coal ash is used as a cement raw material and concrete admixture, and large amount of the ash is also used as land fill material with small value.

Fly ash occupies 90% of coal ash. Three kind of concrete whose binder is steel slag are introduced with or without fly ash.

3.2 Fly ash-steel slag concrete (FS concrete)

Fly ash-steel slag concrete (FS concrete) is a concrete made from blast furnace slag cement, blast furnace coarse aggregate (20-05mm), steelmaking slag (10-00 mm grain size un- adjusted) and coal ash (non-JIS ash, coarse grain only) which is made from by-products except portland cement. It was found the expansion of steelmaking slag is prevented by using with fly ash after adjusting to grain size of a fine aggregate by crushing [3].

The reaction of water and free-CaO is promoted by autoclave curing. It is proven that the intensity ratio lowers when the FA/steelmaking slag ratio is small. That is to say, the strength after autoclave curing is higher, as the FA/slag ratio is bigger. It shows that the long term strength of FS concrete is higher as FA/slag ratio becomes larger. The FA/SL ratio is 1/2-1/4 seems to be adequate. In the FS concrete, the fly ash actively discharges silicate (SiO2--) receiving the alkali stimulation by calcium ion (Ca++) which dissolves from cement and steelmaking slag. The lCaOmSiO2 and nH2O are produced through following reaction.

By this reaction, the generation of Ca(OH)2 is suppressed and the expansion of the slag seems to be restricted. Anti frost damage is lower than plain concrete as the porous blast furnace slag aggregate is used in FS concrete. Especially, it lowers when a blast furnace slag fine aggregate is used. The steelmaking slag is used whose expansion ratio into water is lower than 0.5% through the sufficient aging.

FS concrete is used for making blocks foundation consolidation of harbor, surf break concrete block, concrete for making of upper parts of breakwaters, etc. FS concrete is used 17,000m3 by the 2002 fiscal year. Figure 2 shows a tetra pod products made of Fly ash-steel slag concrete (FS concrete).

Figure 2: Tetra pod made of FS concrete

3.3 Steel slag hydrated matrix

Main constituent material of steel slag hydrated matrix are ground granulated blast-furnace used as binding material and steelmaking slag used as aggregate (maximum size of 25mm). Slaked lime, lime dust etc, for kind I and normal portland cement for kind II are used as alkali stimulant [8]. That is to say, steel slag hydrated matrix is a matrix using latent hydraulic property of blast furnace slag. The granulated blast furnace slag is used as a fine aggregate and fly ash is used as an admixture. In this concrete, the fly ash is thought as a pozzolanic. The steelmaking slag used as an aggregate also acts as alkali stimulant, since it is weak alkaline. Figure 3 shows the developments of compressive strength of steel slag hydrated concrete, of natural aggregate, steel making slag aggregate and cement concrete. The compressive strength at 28days is 30～35MP for the cement concrete, 40～45MPa for steel making slag aggregate and 50～55MPa for natural aggregate. Steel slag hydrated matrix is used for various concrete blocks and artificial stones used for harbour construction. PH of the hydrated matrix is smaller than plain concrete.

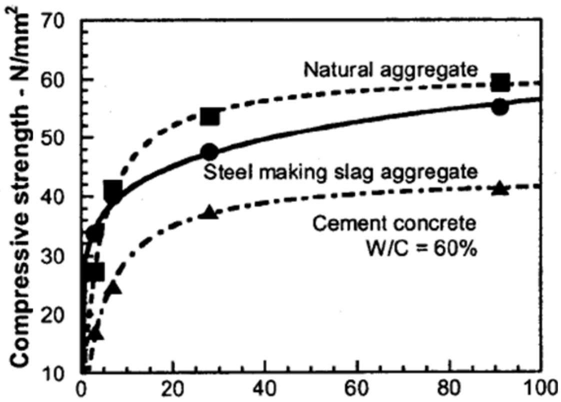

Figure 3: Development of compressive strength of steel hydrated slag concrete [2]

4. Municipal Slag Concrete

4.1 Ground granulated slag

In Japan, part of the municipal wastes are fused at a high temperature more than 1,200 °C to adapt the upper limit of dioxins in the residual material regulated in the "dioxins countermeasure special action law" enforced in January 2000 and reexamined in December 2002. The fused material discharged from the furnace is cooled rapidly with water, and the granulated slag is produced. Figure 4 shows a recycling system of municipal wastes used as a cementitious material for the production of concrete products.

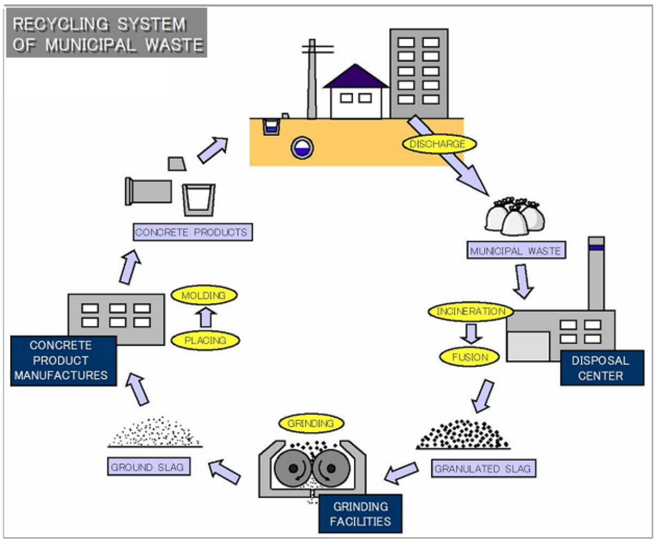

Figure 4: Recycling system of municipal wastes used as a cementitious material for the production of concrete [1]

Table 1 shows the chemical composition of two kinds of slag which were made in two cities that CaO content of municipal slag is smaller than that of the blast furnace slag [1]. The basicity b is one of the indexes which evaluate the hydraulic property of blast furnace slag as an admixture, and it is calculated by Equation 1.

$$\text{Basicity (b)} = (Al2O3 + CaO + MgO) / SiO2 \qquad (1)$$

Table 1: Chemical Composition of Slag

Oxides	Slag A (%)	Slag B (%)
SiO_2	42.2	44.4
Al_2O_3	18.0	13.4
Fe_2O_3	2.8	2.4
CaO	28.2	30.8
MgO	3.5	2.7
SO_3	0.7	0.6
Na_2O	1.4	2.5
TiO_2	1.7	1.0
Basicity (b)	1.18	1.06

The basicity of molten slag from municipal waste is smaller than the standard value 1.60, which is the regulated value of the ground granulated blast furnace slag.

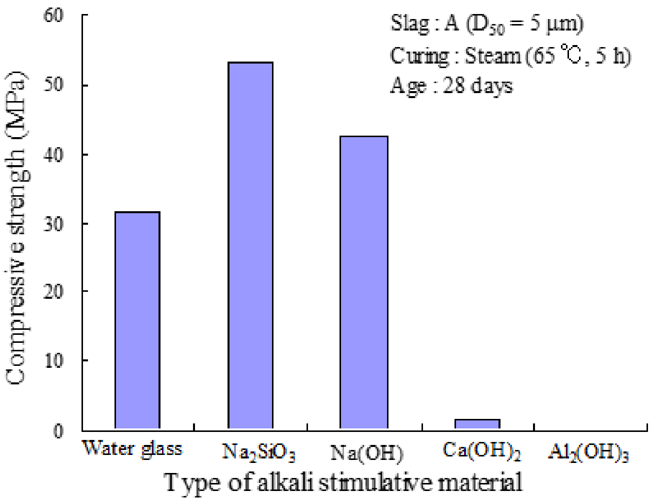

Figure 5: Influence of different kinds of the alkali simulative material on the compressive strength of mortar [2]

Five kinds of alkali simulative materials, namely water glass, sodium meta silicate, sodium hydroxide, calcium hydroxide and aluminum hydroxide were compared. The influence of different kinds of the alkali simulative material on the compressive strength of mortar at the age of 28 days is shown in Figure 5. High compressive strength of about 50～55MPa is obtained, when sodium meta silicate is used as the alkali simulative material. It was confirmed that various factors such as dosage of the alkali stimulation material and average particle size of the slag powder have influences on the compressive strength of the mortar.

5. Conclusions

The cement industry embraces environmentalism enthusiastically by using of waste and by-product as raw material and energy resource for the production of cement. The system that manufactures eco-cement using incinerated ash as the main raw material or that manufactures portland cement as raw material and energy resource after getting rid of chlorine by washing has been developed. In addition, the system, which converts into raw material and energy resource by decomposition of garbage itself, has been also developed. In addition, the matrixes that is made from ground granulated blast furnace slag utilizing its latent hydraulic property and fly ash utilizing its expansion control property with steelmaking slag. The technique that makes a large scale block by blowing carbon dioxide gas to the mixture of the steelmaking slag. As well, the municipal waste molten slag or from the low calcium fly ash and the alkali stimulant has been developed. The results clarify that the new cement manufacturing has been provided a fundamental understanding of the characteristics of new cement for covering various aspects of concrete technology for the creation of "Safety", "Environment" and "Comfort" that is required for the sustainable future of the urban environment.

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