- Technical Paper -

ENVIRONMENTAL IMPACT OF WASTE CONCRETE TREATMENT IN PRECAST CONCRETE PRODUCTION

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ABSTRACT

As one of the approaches to promote the reduction of environmental load in concrete and concrete structure in general, this paper aims to estimate the amount of emissions (CO_2, SO_x, NO_x and PM) as results of waste concrete treatment in precast concrete production by using the emission inventory data and also to propose a better approach regarding to this matter. Surveys to some plants were made to investigate the real situation of its application. It was found that small-sized products plants produced the highest emissions per ton of concrete compared with other types of plants.

Keywords: environmental impact, emission, waste concrete, precast concrete production.

1. INTRODUCTION

One of the major challenges of our present society is environmental conservation. Environmental problems, such as global warming, acidification, resource depletion, waste disposal, air pollution, etc. are some of the problems that should be considered right now in any aspect of the human activities. Construction activity is no exception. In addition, the responsibility of being one of the countries that signed and ratified the Kyoto Protocol strengthens the reason why this environmental conservation is so important to be considered in Japan.

The government and key stakeholders in the construction industry are in their best efforts to reckon the environmental impact as one of the criteria in infrastructure design. Therefore, emission inventory data have been developed and introduced to the industry to evaluate the impact.

According to Cement Sustainability Initiative (CSI) [1], the production of concrete worldwide has reached 25 billion tonnes per year; it means 3.8 tonnes per capita each year. As it provides an easily shaped, cost-effective, fire resistant, durable and strong material for nearly all types of infrastructural installations, buildings and houses, concrete has been popular for the last decades. In fact, it is used twice than the total of all building materials, including wood, steel, plastic and aluminum.

However, the increase of concrete consumption also leads to the increase of the waste which is becoming a worldwide problem nowadays. Some countries are really concern due to the severity of this problem in their countries and thus trying to propose and develop some ideas in order to solve the problem.

As an example, Japan has introduced a concept of *Sound Material-Cycle Society* since 2001, in which the consumption of natural resources is minimized and the environmental load is reduced as much as possible. It is established by promoting reduction, reuse, recycling, heat recovery and appropriate disposal [2]. Moreover, in answering the challenges of sustainable development of concrete, together with Japan, some countries such as United Kingdom, USA, Switzerland, Belgium, Netherland, etc. have promoted the use of recycled concrete aggregate as roadbed, fill material and occasionally as aggregates in new concrete for structural use. However, in many parts of the world, this concrete wastes were usually ended up as unnecessary waste in landfill.

The concrete wastes can be produced as the production wastes in precast concrete production and returned fresh concrete from concrete transport trucks but the most significant source of the wastes comes as construction and demolition wastes. More than 900 million tonnes per year of concrete waste are produced in Europe, USA and Japan itself; 510 million, 317 million and 77 million tonnes, respectively. These numbers do not include the wastes produced in other countries, such as China and India as the biggest cement producers in the world.

Aside from problems such as depletion of natural resources and limited landfill sites, waste concrete also generates problems through its disposal and recycling activity. It is believed that this activity may produce some amount of emissions that contributes to the global warming and acidification in relation to the use of energy in the processing. Although the amounts of emissions from this activity are not as significant as the ones emitted from cement manufacturing, it is obvious that disposal and recycling activity has been one of the potential sources of emissions that should be considered for future benefit.

For this reason, as the starter, this paper will discuss in detail about the emissions of CO_2, SO_x, NO_x, and particulate matter (hereafter abbreviated as PM) as

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a result of disposal and recycling activity (waste concrete treatment) based on the common approaches in Japan. Based on some parameters available in the emission inventory data, the emissions in some case studies were evaluated. This approach aims to show the application of inventory data for environmental impact assessment in real cases. Due to the high demand of precast concrete in infrastructure works in Japan, the case studies were done only in precast concrete production plants and for this reason, it should be noted that the amount of waste concretes that would be discussed in this paper only represent the ones that came as production wastes. Focusing on the environmental impact reduction, other approaches of disposal and recycling activity for these case studies will also be suggested at the end of the discussion.

In the future, this research will be continued to examine the emissions as result from other groups of emission sources such as from the use of energy and material, transportation, construction work/equipment and demolition work/equipment. At the end, it is hoped the total emissions which contribute to the global warming and acidifications in concrete structure can be thoroughly determined.

2. EMISSION INVENTORY DATA

According to *Assessment for Environmental Impact of Concrete: Part 2 (Japan Society of Civil Engineers)* [3,4], the emission inventory data collection is classified into 6 groups, i.e. energy, transportation, construction material, construction work/equipment, demolition work/equipment, and disposal and recycling with 48 detail items in total and 139 parameters included on them. Although it is not completely done, the present inventory data collection has revealed most of the unit-based emission values for CO_2, SO_x, NO_x, and PM on each parameter. The efforts to fill up the rest and adding some other items and parameters for future use are still in progress. Table 1 shows the detail items included on each group.

Table 1 Details on emission inventory data

No	Group	Detail Item
1	Energy	Coal, electricity, gasoline, light oil, heavy oil, kerosene, natural gas, LNG, LPG, city gas, acetylene gas
2	Transportation	Truck, dump truck, agitator truck, freight car, ship
3	Material	Cement, aggregate, mineral admixtures, steel
4	Construction work/equipment	Ready mix concrete production, concrete placing, compaction, curing, excavator, crawler crane, truck crane, wheel crane, motor grader, road roller, tire roller, tamper, sprinkler, and diesel generator.
5	Demolition work/equipment	Plain/unreinforced concrete, prestressed and reinforced concrete, steel reinforced concrete, earth concrete floor, tunnel, pavement, steel/steel frame, demolition machine, breaker, and waste piling and loading activity.
6	Disposal and recycling	Landfill, recycling

Since this paper focuses only on waste concrete treatment, Table 2 shows the unit-based emission values of some parameters, in this case common approaches of the disposal and recycling activity in Japan. Basically, the emissions were estimated based on the amount of energy such as electricity, light oil, heavy oil and kerosene used for operating the machinery/equipment to convert the waste into certain type of recycled aggregates. These values can be used for processing the waste of both precast and casting in-situ concrete products where similar procedures are done in this case. All concrete waste has to be transformed into hardened concrete before it can be processed or recycled.

Table 2 Emission inventory data for disposal and recycling activity

Item	Unit-based emission value (kg/t of waste)			
	CO_2	SO_x	NO_x	PM
Landfill site for wastes				
Leachate controlled (t)	3.3	0.00447	0.0255	0.00198
Non leachate controlled (t)	1.6	0.00126	0.0246	0.00124
Recycled aggregate				
Type III*, 14-30t/h, treated in situ (t)	1.6	0.00120	0.0164	0.00119
Type III*, 35-85t/h, treated in situ(t)	1.3	0.000993	0.0135	0.000980
Type III*, 47-100t/h, treated in situ (t)	1.2	0.000934	0.0127	0.000922
Type III*, 30t/h, treated outside the site (t)	2.3	0.00101	0.00866	0.000524
Type I** (t)	5.7	0.00220	0.0101	0.000763
Type I**, heating and rubbing method (t)	43.6	0.0165	0.139	0.00624

Notes:
* Type III aggregate according to MOC is similar to type L according to JIS (JIS A 5023).
** Type I aggregate according to MOC is similar to type H according to JIS (JIS A 5021).

For the disposal of concrete and other related construction wastes, the common approaches are sorted out into leachate-controlled and non leachate-controlled. As for recycling activity, the approaches are differentiated by the types of the end-products, i.e. type I, type II and type III of recycled aggregates. The characteristics of those aggregates are described in *Tentative Quality Specifications for Reusing Materials from Demolished Concrete for Construction Works*, issued by Ministry of Construction (MOC) Japan in April 1994 (see Table 3).

Table 3 Quality of recycled aggregate (MOC, 1994)

Class	Coarse Aggregate		Fine Aggregate	
	Absorption	Soundness	Absorption	Soundness
I	< 3%	< 12%	< 5%	< 10%
II	< 3% and < 40% or < 5% and < 12%		< 10%	-
III	< 7%	-	-	

Type II and III recycled aggregates are mostly used as roadbed and filling materials, as well as other non-structural concretes. Meanwhile, the type I recycled aggregate which is highly treated with heating and rubbing method is commonly used as coarse and fine aggregates for structural concretes. In addition, the fine by-product powder which is generated in the production of the recycled aggregate can be used for many applications such as cement material and ground improving material in addition to road bottoming, concrete addition, asphalt filler and inorganic board material.

Furthermore, the amount of emissions from disposal and/or recycling activity can be determined by multiplying the unit-based emission values for each type of emissions of each parameter as stated in Table 2 by the amount of each parameter used or consumed or produced in one period of time (in this case, the amount of waste which is disposed or recycled).

3. CASE STUDIES

Based on surveys conducted in some areas in Japan, a few of the precast concrete production plants could be classified into the types of products. There are popular, large-sized and small-sized products. Popular product is described as a product that is normally used in infrastructure work in Japan, such as the hollow block pipe, drainage products, and the boundary block to separate footpath and traffic lane. A big size and/or heavy weight product such as culvert, slab and special product is classified under large-sized product. As for small-sized product, it is described as a product that can easily be carried like the one that is usually sold at a home centre such as small drainage block, gardening block, etc.

There is no significant difference among these 3 types of precast concrete products in terms of raw material procurement, transportation and recycling activity. However, there is a difference in terms of its manufacturing/production. In small-sized product plants and popular product plants, line machine system is normally used. The specified mold is set up in the system and later on, the concrete casting will be done automatically. Meanwhile, in large-sized product plants, specified mold is usually set up in open space because of the size constraint and followed by the manually concrete casting. In terms of demolition activity, it will not be discussed here or calculated in the emission inventory data since most of the cases in Japan, it is done by demolition company dependently. In other words, the emission burden will be transferred to this company rather than owned by the precast concrete company.

According to the data obtained, the total amount of precast concrete production in 12 plants observed for this paper was reaching a number of 303,343 tonnes in one year (2007-2008). 5 out of 12 plants were producing the large-sized products, 4 plants were producing popular products and the rest were producing small-sized products. The biggest amount of precast concrete production was produced from plants of the large-sized products, representing 49.88% of total amount of production with 151,816.8 tonnes, followed by 39.61% of popular products with 120,562 tonnes and only 10.5% of small-sized products with 31,964 tonnes (see Fig. 1).

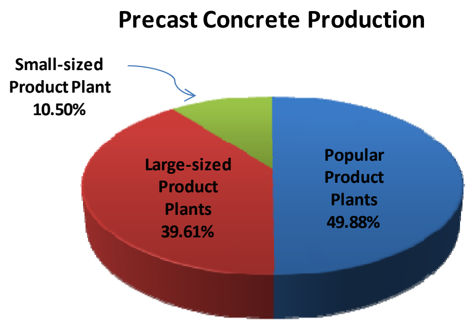

Fig.1 Amount of precast concrete production

4. RESULTS AND ANALYSIS

It has been known when dealing with concrete wastes, precast concrete production produces much lower amount of wastes compared to the ordinary in-situ concrete production. Some of the reasons are more precise estimation of material quantities, lesser transportation and better technology/technique used in pouring process. However, *zero-waste* scenario is still hard to be achieved in practical.

The results showed that the amount of production waste varies with different types of products. Based on the observation, it was found that plants of small-sized products generated in average the highest amount of concrete wastes which was 6.07% of their total production, followed by plants of popular products with 4.45% and plants of large-sized products with only 2.96% (see Table 4).

Table 4 Amount of concrete production and waste per year, based on type of plant

No	Type of Plant	Amount of Production (t/year)	Amount of Waste (t/year)	% of Waste
1	Popular product plant	120,562	5,368.1	4.45
2	Large-sized product plant	151,816.8	4,501	2.96
3	Small-sized product plant	31,964	1,938.7	6.07

Although the statistics in Japan showed that in 2000, 96% of concrete wastes were recycled into type III aggregates, unfortunately the wastes in all plants discussed in this paper were only disposed with leachate-controlled system. Leachate-controlled method is a method to prevent any liquid from a landfill from leaching out and entering the environment. In this case, the waste concrete is defined only as hardened concrete. Fresh concrete waste should be transformed into hardened ones before it can be processed. Furthermore, by using the unit-based emission values as shown in Table 2 for leachate-controlled type, the amounts of emissions per total production in one year could be determined (see Fig. 2).

In Fig. 2, 2 y-axes were created in order to show the result more clearly. The left y-axis is used to show the CO_2 emission per total concrete production in a year, while the other y-axis is used to show either for SO_x, NO_x or PM emission per total concrete production in a year. The result shows that popular product plants produced the highest amounts of emissions per their total production. They generated 17,714.57 kg-CO_2 in a year, followed by large-sized plants with 14,853.30 kg-CO_2 and small-sized plants with 6,397.58 kg-CO_2. The same patterns can be seen with the other types of emissions. Popular product plants generated 24 kg-SO_x, 136.89 kg-NO_x and 10.63 kg-PM emission per year while large-sized product plants generated 20.12 kg-SO_x, 114.78 kg-NO_x and 8.91 kg-PM emission. Small-sized product plant produced the least emissions for any types of emission with 8.67 kg-SO_x, 49.44 kg-NO_x and 3.84 kg-PM emission per year.

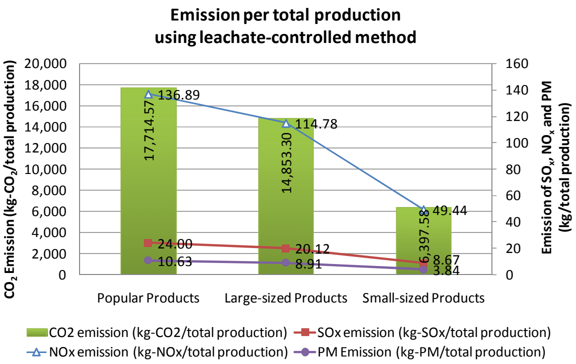

Fig.2 Amount of emissions per total production in a year using leachate-controlled method

In order to show the actual emissions generated per ton of concrete, more calculations were made. Similar with the ones in Fig. 2, 2 y-axes were also created for the same purpose in Fig. 3. Here, it can be seen that the amounts of emissions per ton of concrete show a different trend with those in the previous figure. The amounts of emissions per ton of concrete in plants of small-sized products were in the highest level compared with the ones of other types of plants with 0.20015 kg-CO_2, 0.00027 kg-SO_x, 0.00155 kg-NO_x and 0.00012 kg-PM per ton of concrete production. The popular products plants occupy the second position with 0.14693 kg-CO_2, 0.00020 kg-SO_x, 0.00114 kg-NO_x and 0.00009 kg-PM while large-sized products in the third position with 0.09784 kg-CO_2, 0.00013 kg-SO_x, 0.00076 kg-NO_x and 0.00006 kg-PM per ton of concrete production.

The production efficiency in small-sized product plants somehow showed a lower number compared with those in other types of plants. Within the same period of production time, small-sized product plants produced a higher amount of precast concrete production compared to other types of plants and in consequence, the amount of waste concrete was also higher.

For the purpose of promoting the environmental impact reduction, some other alternatives for disposal and recycling were also being considered for these case studies. The unit-based emission values on each alternative will be different as the amount of energy consumed and also the type of energy are different (see Table 2). Fig. 4 shows the comparison of the amount of emissions among alternatives. They are illustrated in emission ratios, in which the amounts of emissions with leachate-controlled method were used as the reference.

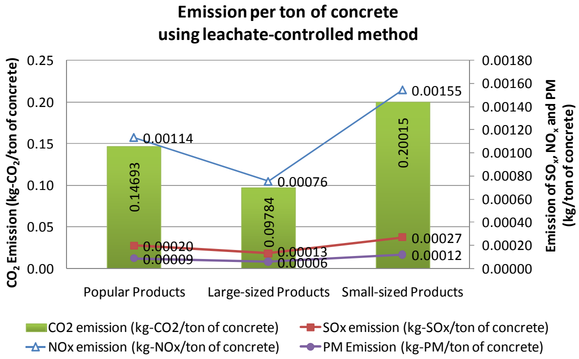

Fig.3 Amount of emissions per ton of concrete using leachate-controlled method

As first alternative, the waste concrete could be disposed without any treatment (non-leachate controlled method). As seen in Fig. 4, the ratios of CO_2, SO_x, NO_x and PM emissions by using this method are lower than those by using leachate-controlled method; 0.48, 0.28, 0.96 and 0.63, respectively. These lower ratios represent smaller amounts of emissions that could be generated by the disposal activity using non-leachate controlled compared to those using leachate-controlled method. However, issues such as limited landfill site which is the priority aspect concerned especially in Japan, and relatively high cost of disposal activity may still persistence and cannot be solved by both methods of disposal. Therefore, this alternative is not so recommended for these case studies.

On the other hand, recycling seems to be the common approach done worldwide in present time regarding to concrete waste management. By recycling, the concrete waste can be processed into a product that can be sold or used for other purposes. Not only can it reduce the environmental burdens by substituting recycled concrete for natural virgin aggregates and conserve the natural sources, but also solve the landfill problems. Landfills are increasing difficult to find in Japan, are too remote from the demolition site, or are too costly to maintain.

For these case studies, few approaches of recycling were proposed and thus calculated by using the unit-based emission values as stated in Table 2. The approaches are listed as follows:

1. Recycled into type III aggregates with different kinds of productivity rates (14-30t/h, 30t/h, 35-84t/h, and 47-100t/h) and different places to process, i.e. treated in-situ or outside the site.
2. Recycled into type I aggregates, either with mechanical rubbing method or heating and rubbing method [5,6].

- In mechanical rubbing method, repeated compaction forces are done using eccentric rotor or screw type of mill to remove mortar from the aggregates.
- The first step in heating and rubbing method is the heating process. The waste concretes are heated up to about 300^{o}C in a heater in order to make cement paste brittle by dehydration. Next, is rubbing process. The heated concretes are rubbed in two mills to remove the cement paste from the surface of aggregates. Coarse and fine aggregates, as well as cement fine powder are obtained as results.

emission, 21% of SO_x emission, 50% of NO_x emission and 47% of PM emission, compared to those using leachate-controlled method.

However, processing the wastes into type I aggregate either with heating and rubbing method or mechanical rubbing method in order to obtain better quality of recycled aggregates should also be considered and encouraged in the future. It should keep in mind that the demand for roadbed material will decrease in time largely due to a decrease in new road construction in Japan, thus it is expected that these waste concretes with better quality can be useful for other applications.

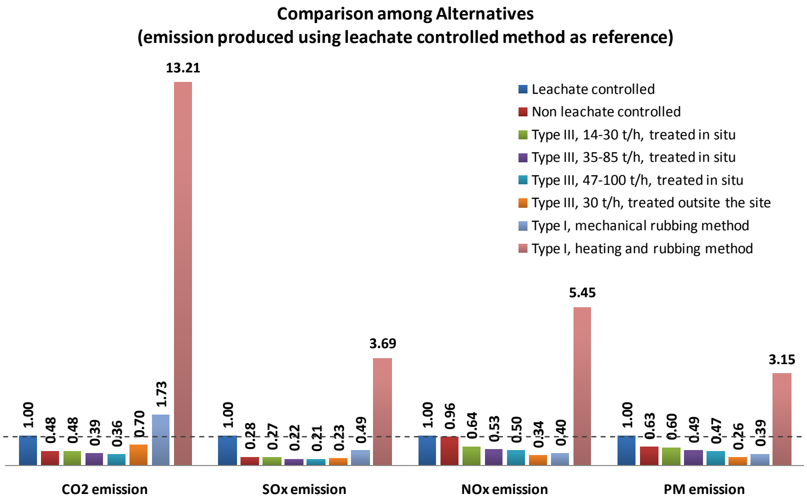

Fig. 4 Comparison among alternatives

In Japan, most of the waste concretes were usually processed into type III recycled aggregates. As it can be seen in Fig. 4, compared to the ones with leachate-controlled method, the CO_2, SO_x, NO_x, and PM emissions of waste concretes which were recycled into type III aggregates, treated either inside or outside the construction site with different kinds of productivity rates would be lower, nevertheless, the opposite results would be found if the waste concrete were recycled into type I aggregates by heating and rubbing method, i.e. 13.21 for CO_2 emission, 3.69 for SO_x emission, 5.45 for NO_x emission and 3.15 for PM emission. It is showed in Fig. 4 that the ratios in all types of emissions using this method are higher than those using other methods due to the high amount of energy consumed to heat and rub the waste concrete. Meanwhile, by recycling the waste concrete into Type I aggregate using mechanical rubbing method, it would only produce higher CO_2 emission with ratio of 1.73 compared to that by disposing the waste using leachate-controlled method. Lower ratios would still be found in the case of SO_x, NO_x and PM emission with 0.49, 0.40 and 0.39, respectively.

To reduce the amounts of emissions for the case studies in this paper, recycling the waste concretes into type III aggregates with productivity rate of 47-100 t/h and treated in situ would be appropriate as the first suggestion. The results would be lower as 36% of CO_2

In addition, although it has been known that heating and rubbing method in concrete recycling emitted a huge amount of emissions compared with the other methods, it may also give more advantages in the future when the scope of life cycle assessment is expanded. By using the by-product cement powder and high qualities of recycled aggregates in the making of a new concrete, the emissions that come from the cement manufacturing and raw material procurement can be reduced. Here, the raw material procurement includes the processes of quarrying, crushing, grinding and also transporting the natural aggregates. It has been known that these processes produce greater emissions than the processes of crushing, recycling and transporting of concrete. In other words, the overall emissions from the concrete industry can be reduced as the ones from cement manufacturing and raw material procurement are the main sources of the emissions.

Aside from disposal and recycling, reusing the waste concretes can also be another alternative. Here, it means reusing a part of concrete in original form or by cutting into smaller blocks. This approach helps the environment by conserving the resources, reducing the wastes and the environmental impact from new construction. Since it depends most on its original durability and has limited stocks, this approach is not so popular. However, improved designs that allow for reusing slab or other parts of concrete structure and structure transformation without demolition could increase this use.

In general, there are some obstacles in making concrete recycling as a mandatory method. They are listed as follows:

1. Low economic cost of natural aggregates in some countries.
2. Unstable supply of concrete wastes.
3. Misconception from some parties about recycled aggregates/concretes. They preferred natural aggregates or new material as they think those things have better quality than recycled ones.
4. In terms of laws, regulations and standards, recycled materials need more considerations and thus, it is more troublesome in some cases.
5. Limitation for special applications, such as high performance concretes makes the use of natural materials seems to be inevitable.

For the reasons mentioned above, all the parties involved in concrete industry should participate and try to upgrade the shortcomings for future use.

At the end, the decision for the most appropriate approach to manage this problem will be different on each plant. It will depend on some factors, such as cost, location, amount of waste, rules/regulations, etc.

5. CONCLUSIONS

(1) Within this study, small-sized product plants generated the highest amount of all types of emissions with 6.07% of the total production, followed by popular product plants in second place and large-sized product plants in the last place with 4.45% and 2.96%, respectively. Within the same period of production time, small-sized product plants produced a higher amount of precast concrete production compared to popular product and large-sized product plants and in consequence, the amount of waste concrete in small-sized product plants was also higher.

(2) Limited to the case studies in this paper, alternative to recycle the waste concretes into type III aggregates with productivity rate of 47-100 t/h and treated in-situ was proposed. This alternative is predicted to give some reductions to the CO_2, SO_x, NO_x, and PM emissions with average numbers of 63%, 79%, 50% and 53% respectively, compared to the leachate-controlled method as the reference. However, recycling the waste concretes into type I aggregates either by mechanical rubbing method or heating and rubbing method can also be an alternative if the overall emissions reduction in the life cycle of concrete structures is being taken into consideration.

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