ENVIRONMENTAL MANAGEMENT OF CONCRETE AND CONCRETE STRUCTURES – TOWARD SUSTAINABLE DEVELOPMENT IN CONSTRUCTION INDUSTRY

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Abstract

Concrete and construction industries have consumed an enormous amount of resources and energy and generated a large amount of wastes. We need to properly manage them from the environmental point of view. In this paper, environmental aspects of concrete and some systems for environmental management in the design of concrete structures are discussed.

Streszczenie

Przemysł betonowy i budowlany pochłonęły ogromną ilość zasobów naturalnych i energii wytwarzając wielkie ilości odpadów. Z punktu widzenia środowiska musimy odpowiednio tymi odpadami zarządzać. Artykuł omawia aspekty środowiskowe betonu oraz niektórych systemów zarządzania środowiskiem w procesie projektowania konstrukcji z betonu.

Keywords: **Concrete; composite-evaluation bid system; environmental aspects; environmental management; environmental design; ISO standards.**

1. INTRODUCTION

The environmental issue has now become the most crucial and serious problem for the continued existence of humankind. The earth's resources and energy have been consumed in great quantities by the rapid industrialization and population growth over a span of more than two hundred years since the industrial revolution, resulting in global environment changes that humankind have never experienced. Fortunately, the humankind has clearly recognized the nature of the problem, creating a concept of "sustainable development", which may be regarded as an environmental revolution. This concept means development that meets the needs of not only the present but also future generations while radically renouncing the conventional economic values-mass production, mass consumption, and mass disposal. Incorporation of the concept of sustainability will be required for all social, economic, and cultural activities in the future.

As a system for coping with such circumstances, ISO has already published environmental standards, ISO 14000 series, which provide general rules related to methods of assessing environmental loads and the environmental declaration based on such assessment. Since these standards primarily cover industrial products and services, ISO 15686-6 and ISO 21930 were developed to cover buildings, which have strong impacts on the environment. The former deals with the basic framework of the procedure for considering the environmental aspects of buildings, whereas the latter deals with that for issuing environmental declaration regarding building products. These can be regarded as standards in which the concept of ISO 14000 is specialized for buildings.

Concrete is used in abundance for buildings and civil structures. Among the 10 billion ton annual concrete production worldwide, cement production, which is known to involve massive amounts of CO_2 generation, accounts for 2 billion tons, and this amount is expected to multiply two to three times in the future.

The massiveness of the quantity of resources used for concrete is understood in consideration of the fact that the world's current annual material flow is approximately 26 billion tons. The resulting massive stock is ultimately demolished, and the disposal of the huge amount of concrete lumps places a heavy burden on the environment.

Thus, the construction and the eventual demolition of concrete structures require a huge amount of resources and energy, and as a result, a lot of materials that place burdens on the environment are emitted. Therefore, it is highly important for the concrete sector to clearly understand the environmental aspects of the sector and the current status of such aspects, and to build up a system for appropriate environmental management in order to reduce environmental burdens. In so doing, it is essential to develop a system for rationally conducting the environmental design of a concrete structure.

In this paper, the environmental aspects of concrete and related technologies are outlined, and the current status and future prospects of some systems for environmental management, that reduces the environmental burdens of concrete and concrete structures, are discussed. In addition, some examples of the environmental design of a concrete structure are shown to get the future perspectives of environmental design.

2. ENVIRONMENTAL ASPECTS IN CONCRETE

2.1. Aggregate

It is said that, of the approximately 26 billion tons of annual material flow throughout the world, aggregate used as a construction material accounts for some 20 billion tons [1]. In other words, natural sand, gravel and crushed stone exist most abundantly in the natural world, thus these materials are most frequently used for infrastructure development. Although the aggregate situation varies by country and region, the replacement of natural aggregate with crushed stone aggregate has progressed in recent years due to environmental restrictions. It is believed that this has also led to changes in the quality of aggregate, which greatly affects the quality and durability of concrete. Crushed stone aggregate usually has sharp edges, thereby increasing the water content of concrete, and the energy used for the production of crushed stone has an adverse impact on the environment. Moreover, the development of quarries is also causing environmental problems.

In recent years it has been said that infrastructure development has matured in Japan. While the number of national highways and bridges 50 years or older managed by nation and local governments in Japan was 8,191 in 2005, it is expected to increase to 63,494 by 2025 [2]. Reconstruction of structures is also increasing in urban areas. According to the estimate by the Development Bank of Japan [3], the total amount of concrete masses to be generated in 2025 is estimated to be 210 million tons, which is a twofold increase of the 112 million tons generated in 2005. These amounts are extremely high, considering that the total concrete production for Japan in 2005 was approximately 285 million tons. While most concrete masses have been used as base course materials, their demand is expected to decrease dramatically. Since the use of these as recycled aggregate is crucial considering the pressure on waste disposal sites and the preservation of aggregate resources, the development of technologies for recycled aggregate production is being promoted.

Technologies for recycled aggregate production in Japan include the heating and rubbing [4], eccentric-shaft rotor [5] and mechanical grinding [6] methods. In the heating and rubbing method, concrete masses are heated at 300 deg. Celsius and the cement paste content is weakened to remove mortar and cement paste from the aggregate. Figure 1 shows an overview of a recycled aggregate production system using this method. Figure 2 illustrates the recycled coarse and fine aggregate produced by the system. While the production of recycled aggregate generated a large amount of fine powder, it also indicated the possibility of using fine powder like this as a substitute solidification material for the deep mixing stabilization method (soil cement walls) [7]. In the eccentric-shaft rotor method, crushed concrete lumps are passed downward between an outer cylinder and an inner cylinder that eccentrically rotates at a high speed to separate it into coarse aggregate and mortar through a grinding effect. Figure 3 presents an overview of a recycled aggregate production system using this method. Mechanical grinding is a method used to produce coarse and fine aggregate by separating a drum into small sections with partitions, loading the drum with iron balls for grinding and rotating the partitions. Figure 4 shows an overview of the recycled aggregate production system using this method. The coarse aggregate produced by these methods has been used for actual construction projects.

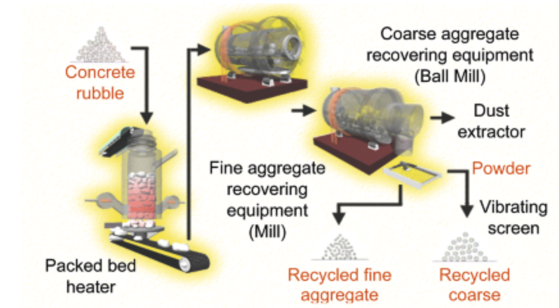

Figure 1.
Production technology of recycled aggregate (heating and rubbing method)

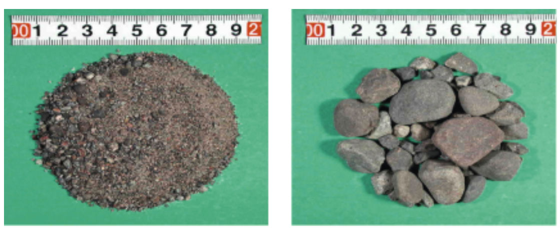

Figure 2.
Recycled aggregates by heating and rubbing method

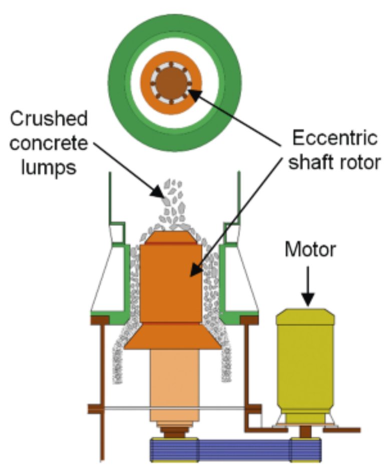

Figure 3.
Production technology of recycled aggregate (eccentric-shaft rotor method)

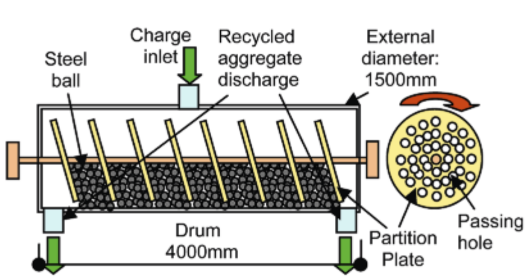

Figure 4.
Production technology of recycled aggregate (mechanical grinding method)

In Japan, JIS A 5021[8] was established in 2005 as a standard for high-quality recycled aggregate H for concrete, which is produced through advanced processing, including crushing, grinding and classifying, of concrete masses generated in the demolition of structures. Recycled aggregate H must have physical properties satisfying the requirements listed in Table 1. There are also upper limits for the amounts of deleterious substances contained in recycled aggregate H, as shown in Table 2. JIS A 5023 has also been established as a standard for recycled concrete using low-quality recycled aggregate L. This type of concrete includes backfilling, filling and levelling concrete, and the use of Type B blended cement and admixture is required as a measure against alkali-silica reactivity.

Table 1.
Physical properties requirements for recycled aggregate H

Items	Coarse aggregate	Fine aggregate
Oven-dry density, g/cm^3	not less than 2.5	not less than 2.5
Water absorption, %	not more than 3.0	not more than 3.0
Abrasion, %	not more than 35	NA
Solid volume percentage for shape determination, %	not less than 55	not less than 53
Amount of material passing test sieve 75μm, %	not more than 1.0	not more than 7.0
Chloride ion content, % (NaCl)	not more than 0.04	

Table 2.
Limits of amount of deleterious substances for recycled aggregate H

Category	Deleterious substances	Limits (mass %)
A	Tile, Brick, Ceramics, Asphalt	2.0
B	Glass	0.5
C	Plaster	0.1
D	Inorganic substances other than plaster	0.5
E	Plastics	0.5
F	Wood, Paper, Asphalt	0.1
Total		3.0

Production of recycled aggregate usually involves greater energy use compared with that of virgin aggregate, thus leading to greater environmental impacts. While finding ways to deal with these environmental impacts as an external cost is a major issue, it would be ideal to absorb this cost in the entire production/use system of recycled aggregate. As shown in Figure 5, Kuroda et al. [9] established an on-site concrete resource recycling system from this standpoint, and proved that CO_2 emissions from the system were lower than those in which it was used as a conventional base course material. This was achieved by reducing the amount of transported material and the use of fine powder as a substitute solidification material for ground improvement. Yanagibashi [10] studied CO_2 emissions in cases of use of recycled aggregate for base course material made of concrete masses, use of recycled coarse aggregate for concrete and recycled sand for base course and backfill materials, and use of recycled coarse aggregate for concrete and the remaining amount for cement clinker. The paper concluded that the use of recycled aggregate was an environmentally friendly method that could contribute to the preservation of natural aggregate since CO_2 emissions were nearly identical.

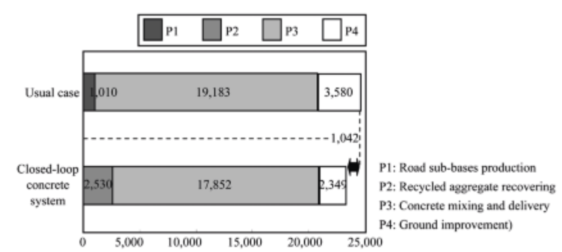

Figure 5.
CO_2 emission in usual and closed-looped concrete recycle system

Iron and steel slag is also used as aggregate. In 2005, 25,747,000 tons of blast-furnace slag and 14,897,000 tons of steelmaking (converter and electric-furnace) slag were generated in Japan [11]. Of these, blast-furnace slag was primarily used as aggregate for concrete, and its amount was 3,158,000 tons.

While fly ash has been used as a substitute admixture for cement, the idea of using this as fine aggregate has emerged in recent years [12]. Considering the worldwide increase in fly ash production expected in the future, it is desirable to design a mix that integrates substitutes for cement and fine aggregate.

In recent years, melting treatment of waste and sewage sludge has become common in Japan due to pressures on waste disposal site and problems related to dioxin and heavy metals. Molten slag is generated as a residue after melting treatment. In 2004, 144 waste and 18 sewage sludge melting treatment facilities were in operation throughout Japan, producing 480,000 and 44,000 tons of molten slag, respectively. Waste molten slag production is estimated to reach as high as 2.7 million tons in the future. Melting treatment was also commenced in 2005 for 600,000 tons of illegally dumped industrial waste in Teshima, Kagawa Prefecture [13]. Approximately 300,000 tons of molten slag is to be produced for 10 years, and the prefecture government has decided to use the entire amount as aggregate for concrete. Basic studies on the application of municipal solid waste and Teshima molten slag to concrete have been conducted [14], [15]. Molten slag is characterized by low water-retentivity since it is vitreous. When it is used in large amounts, bleeding increases and leads to a decease of the strength of concrete and, in case of reinforced concrete, a decrease in the bond of reinforcing bars to concrete. The permissible replacement ratio of molten slag for fine aggregate thus varies according to the performance required for concrete. It is also necessary to pay attention to aluminum, which is a metal contained in molten slag, since it may cause expansion and deterioration of concrete as it reacts with the alkali of cement and generates hydrogen. In Japan, JIS A 5031 [16] was established for molten slag aggregate for concrete. Table 3 lists the physical properties of molten slag required by this standard.

Table 3.
Physical properties requirements for molten slag aggregates

Molten slag Items	Coarse aggregate	Fine aggregate
Oven-dry density, g/cm^3	not less than 2.5	not less than 2.5
Water absorption, %	not more than 3.0	not more than 3.0
Soundness, %	not less than 12	not less than 10
Solid volume percentage for shape determination, %	not less than 55	not less than 53
Amount of material passing test sieve $75\mu m$, %	not more than 1.0	not more than 7.0

2.2. Cement

Cement is the most important basic material for infrastructure development. There are two aspects of cement production and its relation to the environment – CO_2 emissions and the use of waste as a raw material and fuel. Japan's cement production, including blended cement and export, has amounted to more than 800 million tons in the last 10 years. The world's cement production is thought to be approximately 2 billion tons at present. Figure 6 shows the cement demand predicted by Humphreys et al. [17]. According to this prediction, production is expected to reach approximately 4 billion tons 30 years from now. Figure 7 displays the CO_2 emission unit of cement production in each country/region. Based on the mean value 0.87(kg-CO_2/kg-Cement) of these, CO_2 emissions from cement production totalling 4 billion tons is estimated to be approximately 3.5 billion tons, which is 2.7 times as high as Japan's current total CO_2 emissions (approx. 1.3 billion tons). Also, based on the lowest CO_2 emission unit of Japan (0.73), the world's CO_2 emissions are expected to reach approximately 2.9 billion tons 30 years from now. This means that the world's cement-originated CO_2 emissions can be reduced by approximately 8% through the use of Japan's cement production technology.

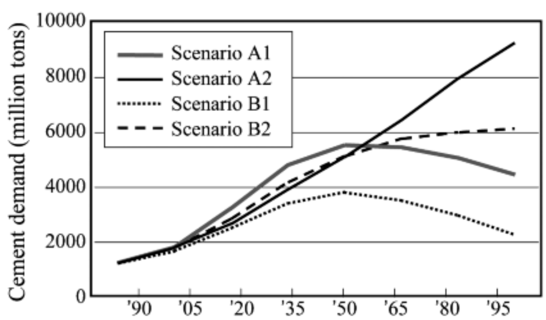

Figure 6.
Estimated cement demand

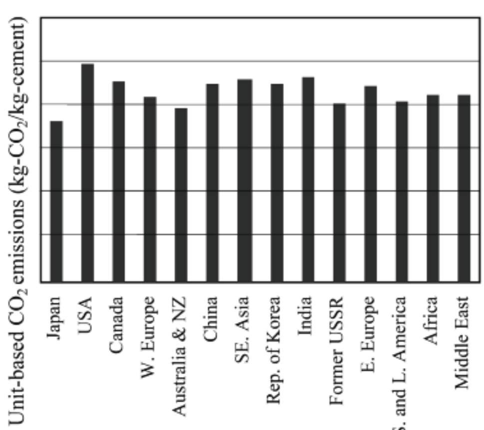

Figure 7.
Unit-based CO_2 emission in cement manufactures

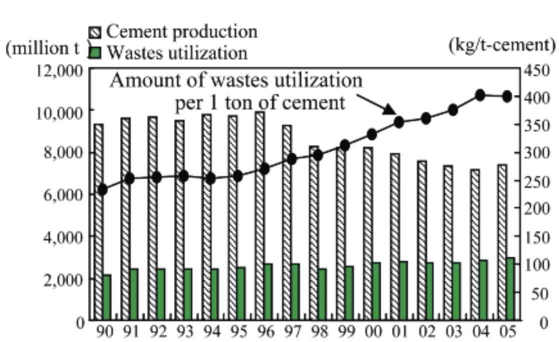

Figure 8.
Amount of wastes utilization for cement production in Japan

Nearly 30 million tons of waste and by-products are currently used as raw materials and fuels for cement production in Japan. Such raw materials include blast-furnace slag, fly ash and sewage sludge, and fuels include waste tires and plastic. Figure 8 illustrates the changes in cement production and use of waste and by-products in Japan. It can be seen that the use of waste and by-products is steadily increasing while cement production is decreasing. The cement industry is setting a target value of 400 kg/t-cement for 2010. Figure 9 shows an international comparison of energy consumption per ton of cement clinker, in which Japan displays incomparably high energy efficiency. It can be seen from this that Japan has exceptional cement production technology. This means that CO_2 emissions associated with the construction of concrete structures is being reduced as a consequence.

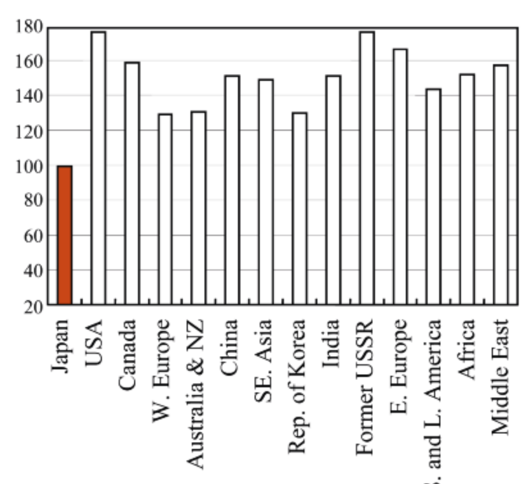

Figure 9.
International comparison of energy consumption in cement-clinker production

2.2.1. Admixtures

It can be said that basic technologies have already been established for the use of admixtures in concrete [18], [19]. Admixtures have been used for concrete for the effective use of industrial by-products and improvement in concrete properties through their utilization. In recent years, however, their importance in the reduction of environmental impacts has also attracted attention.

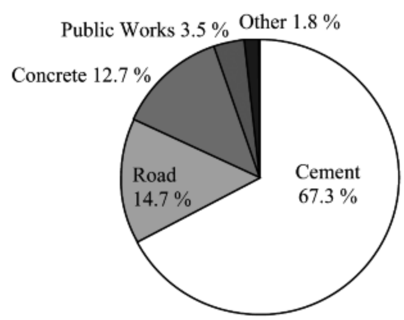

Figure 10.
Utilization of blast furnace slag in Japan

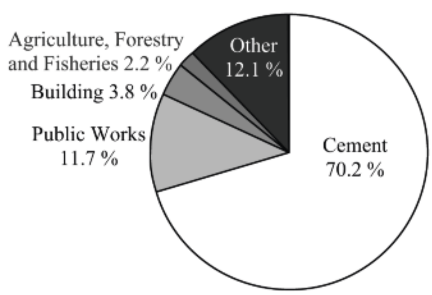

Figure 11.
Utilization of fly ash in Japan

As shown in Figure 10, approximately 67% of blast-furnace slag was used for blast-furnace cement in Japan in 2005. This means that the performance of blast-furnace slag is used in the most rational manner. Figure 11 presents the breakdown of the use of coal ash (9,792,000 tons) in Japan in 2004 [20]. Of the 70% used in the field of cement, the majority was used as a raw material for cement production. Although the amount of fly ash that can be used for concrete is approximately 20% of the total production of coal ash, its use as an admixture for concrete is only about 1%. This situation is not appropriate considering the excellent performance of fly ash as an admixture. Approximately 10% of the coal ash produced in Japan is currently disposed of in landfills.

Figure 12 shows the estimated volumes of admixture production in the world in 2002 and 2020 [21]. In particular, the production volumes of fly ash and blast-furnace slag are expected to increase 1.7 and 3 times, respectively. By effective use of these increased volumes of admixtures, it will become possible to reduce environmental impacts caused by the future increase in concrete demand.

3. SYSTEMS FOR ENVIRONMENTAL IMPACT REDUCTION

3.1. Standardization

According to ISO, the ISO 14000 family consists of standards related to environmental management systems and others which are specific tools for realizing environmental policy and achieving objectives and targets. In the ISO 14000 family, there are ISO 14020 series and ISO 14040 which may be related to concrete.

The framework of ISO 14020 family, Environmental

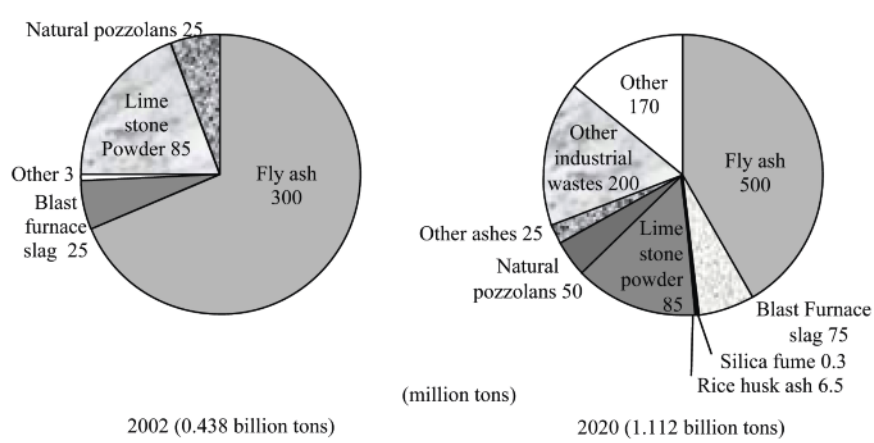

Figure 12.
Estimated world admixture minerals production

labels and declarations, is as follows:

ISO 14020 – General principles

ISO 14021 – Self-declared environmental claims (Type II environmental labelling)

ISO 14024 – Type I environmental labelling – Principles and procedures

ISO/FDIS – Type III environmental declarations – Principles and procedures

ISO 14020 provides guiding principles for the development and use of environmental labels and declarations, the claim which indicates the environmental aspects of a product or service. An environmental label or declaration may, among other things, take the form of a statement, symbol or graphic on a product or package label, in product literature, in technical bulletins, in advertising or in publicity. The objective of environmental labels and declarations is to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market-driven continuous environmental improvement. There are nine principles for environmental labels and declarations. For example, Principle 1 is that environmental labels and declarations shall be accurate, verifiable, relevant and not misleading. Principle 3 is that environmental labels and declarations shall be based on scientific methodology that is sufficiently thorough and comprehensive to support the claim and that produces results that are accurate and reproducible. Principle 5 is that the development of environmental labels and declarations shall take into consideration all relevant aspects of the product life cycle.

ISO 14024 provides the principles and procedures for developing Type I environmental labelling programmes and for assessing and demonstrating compliance. The certificate procedures for awarding the label are also provided. ISO 14021 specifies requirements for self-declared environmental claims, including statements, symbols and graphics, regarding products. In other words, this standard describes a general evaluation and verification methodology for self-declared environmental claims and specific evaluation and verification methods for the selected claims. ISO/FDIS 14025 provides the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. Type III environmental declarations are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication under certain conditions is not precluded.

The framework of ISO 14040 family, Environmental management – Life cycle assessment, is as follows:

ISO 14040 [9] – Principle and framework

ISO 14041 [10] – Goal and scope definition and inventory analysis

ISO 14042 [11] – Life cycle impact assessment

ISO 14043 [12] – Life cycle interpretation

In ISO 14040, it is defined that LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by a) compiling an inventory of relevant inputs and outputs of a product system; b) evaluating the potential environmental impacts associated with those inputs and outputs; c) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. As the general categories of environmental impacts requiring consideration, the use of resource, human health and ecological consequences are raised. The purpose of LCA is to assist in a) identifying opportunities to improve the environmental aspects of products at various points in their life cycle; b) decision-making in industry, government or non-governmental organizations; c) selection of relevant indicators of environmental performance; d) marketing. One of the important things in life cycle assessment is system boundary, which is interface between a product system and the environment or other product systems. In other words, system boundaries determine which unit processes, smallest portions of a product system, shall be included within the LCA.

ISO 14041 specifies the requirements and the procedures necessary for the compilation and preparation of the definition of goal and scope for a LCA, and for performing, interpreting and reporting a life cycle inventory analysis. As the goal of an LCA study, the intended application, the reasons for carrying out the study and the intended audience shall be stated clearly. The scope of the study shall consider all relevant items in accordance with ISO 14040. A life cycle inventory analysis (LCI) is concerned with the data collection and calculation procedures.

The purpose of life cycle impact assessment (LCIA) is to assess a product system's life cycle inventory analysis (LCI) results to better understand their environmental significance. The LCIA phase models selected environmental issues, called impact categories, and use category indicators. Impact category is class representing environmental issues of concern to which LCI results may be assigned. Climate change, acidification etc. are the examples of impact category. Category indicators are intended to reflect the aggregate emissions or resource use for each impact category. Category endpoint is considered as the attribute or aspect of natural environment, human health or resources, identifying an environmental issue of concern. For example, the category endpoints due to acidification are forest, vegetation, etc.

The purpose of life cycle interpretation is to summarize and discuss the results of LCI and LCIA or both as a basis for conclusions, recommendations and decision-making. In other words, the objectives of life cycle interpretation are to analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the LCA or LCI study and to report the results of the life cycle interpretation in a transparent manner.

ISO 15686 family is the standards on Buildings and constructed assets – Service life planning , which consist of the followings:

Part 1 – General principles
Part 2 – Service life prediction procedures
Part 3 – Performance audits and reviews
Part 5 – Whole life costing
Part 6 – Procedures for considering environmental impacts
Part 7 – Performance evaluation for feedback of service life data from practice
Part 8 – Reference service life

These standards cover buildings and everything that is constructed, including civil engineering structures. Service life planning, which may be called service life design, is the preparation of the brief and design for the buildings and constructed assets and its parts to achieve the desired design life, for example in order to reduce the costs of building ownership and facilitate maintenance and refurbishment.

ISO 15686 Part 6 describes how and when to include environmental aspects into the design of buildings and constructed assets. It provides a procedure for assessing the relative environmental impacts of design options and also it identifies the interface between environmental life cycle assessment and service life planning. In order to make meaningful comparisons of options, their functional equivalency should be determined. After identifying functionally equivalent options, environmental information for these options should be gathered and assessed in the life cycle. On the other hand, this standard describes that when implementing life cycle assessment in service life planning, it is anticipated, in most situations, the LCA will not be performed within the procedure; rather; existing data sets should be considered and combined in order to model current design option. However, it will be difficult to follow this procedure. It means that this standard is not utilized practically. Therefore, we need to develop a standard, which can be applied for concrete structures.

ISO 21930 [20] is the standard on Sustainability in building construction – Environmental declaration of building products. This standard provides the principles and requirements for Type III environmental declarations of building products. It gives guidelines for the development and implementation of Environmental Product Declaration (EPD) on the life cycle assessment in order to ensure transparency of the methodology applied for developing the EPD for building products. The objective of EDP is to encourage the demand for and supply of building products that cause less stress on the environment, through communication of verifiable and accurate information on environmental aspects of those building products that is not misleading, thereby stimulating the potential for market-driven continuous environmental improvement. The content of EPD includes general information, such as the name and address of the manufacturer, and environmental aspects, such as

1) environmental impacts expressed with the impact category
   - climate change (CO_2-equivalent)
   - destruction of the stratospheric ozone layer (CFC 11-equivalents)
   - acidification of land and water sources
   - eutrophication
   - formation of tropospheric ozone (photochemical oxidants)
   - depletion of renewable energy resources
   - depletion of non renewable mineral resources
2) Use of renewable resources and renewable primary energy
   - use of renewable resources
   - use of renewable primary energy
   - consumption of freshwater
3) Waste to disposal
   - hazardous waste
   - non hazardous waste
4) Emissions to water, soil and indoor air

and additional environmental information, such as impact and potential impact on biodiversity, toxicity related to human health and/or the environment.

EPD will be effective when the related people want to know the impact of the building on the environment. However, if the impacts are not compared with a reference data, it will not work. In other words, the objective of EPD will not be achieved. Therefore, a system to operate this standard should be established.

Concrete is used in abundance for buildings and civil structures. Among the 10 billion tons annual concrete production worldwide, the cement production, which is known to involve massive amounts of CO_2 generation, accounts for 2 billion tons, and this amount is expected to multiply many times in the future. The massiveness of the quantity of resources used for concrete is understood in consideration of the fact that the world's current annual material flow is approximately 26 billion tons. The resulting massive stock is ultimately demolished, and the disposal of the huge amount of concrete lumps places a heavy burden on the environment. In contrast to reinforcement and other steel products, most concrete is used as semi-finished products. After being produced in ready-mixed concrete plants, concrete is placed, consolidated, and cured at the job site. These processes require various other materials, such as supporting and formwork. Also, concrete structures are designed and constructed under various conditions, while involving sludge treatment concomitant with concrete production, as well as the use of supplementary cementing materials such as blast-furnace slag and fly ash as concrete materials. Environmental load assessment is also affected by other important factors. These include policies for the inventory of concrete materials and system boundaries and the transportation methods and route setting of materials and products. Concrete and concrete structures are thus made into their intended forms through such extremely complicated processes. It is therefore exceptionally difficult to directly apply the existing ISO environmental standards without common rules on the environmental aspects at each stage, and more specific standards specialized for concrete are essential for the concrete sector and related sectors. Based on the background, ISO/TV71 established SC8 for developing the environmental standards for concrete and concrete structures (Environmental aspects of concrete and concrete structures).

The basic ideas to develop the standards are as follows:

- The consistency among ISO Environmental Standards shall be kept. ISO XXXXX will be developed from the viewpoint of how ISO 14000 and 15686 series are practically applied for concrete and concrete structures. Namely, it should be usable standard.
- In this standard, a new framework, in which the characteristics of concrete and concrete structures and the existing ISO Environmental Standards are considered, is developed.
- ISO XXXXX provides the procedures to consider environmental aspects regarding manufactures and recycles of concrete, and design, execution, reuse, and demolition of a concrete structure.
- ISO XXXXX provides the procedures to implement the LCA of concrete and concrete structures.
- The pollutions to water, soil and indoor air, and noise and vibration will also be dealt with

Figure 13 indicates the interface between the existing standards and the newly developed standards.

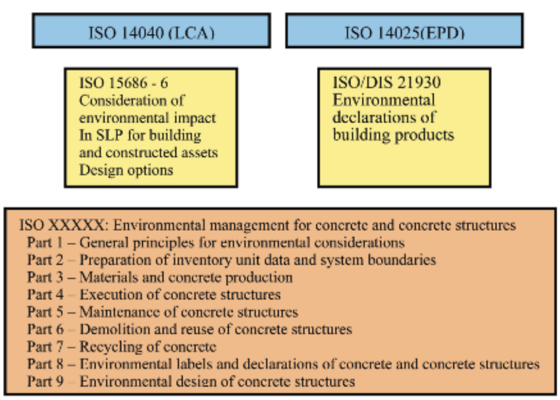

Figure 13.
Interface between the existing standards and the newly developed standards in ISO XXXXX

3.2. Composite-Evaluation Bid System

Generally speaking, in order to reduce environmental impacts associated with the construction of concrete structures, the current state of such impacts must first be known and new technologies and systems introduced. Where goals can be achieved by adopting existing technologies and systems, few major challenges will emerge. However, the reduction of environmental impacts has always been difficult, as it requires the development of new technologies and the introduction of high-cost technologies. This is the reason why the environment has been dealt with as an external diseconomy. Such external diseconomies should be internalized in one way or another and appropriately assessed. This should ideally be guided by market principles, but such incentives will not emerge without the implementation of a reasonable system.

The composite-evaluation bid system is a method to incorporate environmental aspects into a bidding process. Introduction of this method has started recently in Japan, but the way the system is used is rather primitive and the environmental aspects hardly function. Traditionally, successful bidders are the ones who submit the lowest bids using standard design and construction methods. The composite-evaluation bid system, on the other hand, assesses a non-price factor (technical capacity) as well, and bidders are assessed technically and monetarily. The assessment score is calculated by the following formula:

$$\text{Assessment score} = (\text{Basic point} + \alpha + \beta)/\text{Bidding price} \quad (1)$$

Where, the basic point is a standard point and the full 100 points are awarded when all requirements are met, α is a technical proposal point (max. 70 points), and β is an execution system point (max. 30 points). In short, compared with the case where α and β are zero, this system allows the maximum planned price to double, and any increase in cost due to the introduction of environmental technologies can reasonably be absorbed.

To apply environmental technologies to concrete structures and incorporate them in the composite-evaluation bid system, the substance of technical proposals and their reasonable and objective evaluation are essential. The reason why the application of the composite-evaluation bid system is difficult, despite its availability, is that technical development related to concrete has not been pursued from environmental perspectives, and therefore, assessment principles for environmental technologies have not clearly been established. It is hoped that the composite-evaluation bid system will provide future incentives for the development of environmental technologies in the field of concrete.

4. ENVIRONMENTAL DESIGN

4.1. JSCE Recommendation of Environmental Performance Verification for Concrete Structures [22]

The Japan Society of Civil Engineers (JSCE) published the Recommendation of Environmental Performance Verification for Concrete Structures (draft) in 2005. This Recommendation provides general principles of consideration concerning environmentality when conducting design, construction, use, maintenance/management, dismantling, disposal and reuse after dismantling of a concrete structure. Its purpose is to extend the application of performance verification concept on safety, serviceability and durability of concrete structures to the "environment." The Recommendation consists of chapters on general rules, environmentality, evaluation and verification of environmental performance, inspection and records. The following are listed as items that must be taken into account when considering the environmental aspects of concrete structures:

- Greenhouse gas, air contaminants, resources/energy, waste
- Water and soil contaminants
- Noise/vibration
- Others

The following are also provided as methods to be used for evaluation of environmental performance:

- LCA method for evaluation of the emission of greenhouse gasses and air contaminants, consumption of resources/energy, waste generation, etc.
- Appropriate testing and measurement methods for identification and quantitative evaluation of the substances causing water and soil contamination
- Direct measurements, reliable prediction methods or a combination of both for evaluation of noise, vibration, etc
- Others

The Recommendation also gives examples of basic environmental impact units and integration factors necessary for evaluation of environmental performance related to design, construction and other aspects of concrete structures.

The verification of environmental performance is the act of confirming that the value of performance retained by a structure (R) is larger (or smaller) than the set value (S) based on the performance requirements for the structure concerning the environmental aspect subject to the verification. For example, verification of CO_2 emissions can be passed if the calculated value of CO_2 associated with an actual structure is smaller than the absolute value of CO_2 emissions set as the performance requirement (or the value based on the reduction rate from the standard value). In case of the use of a byproduct, the minimum amount that must be used is set as the performance requirement, which is satisfied if the amount used for a structure is larger than this value. While environmental performance requirements may include legal regulations, demands of the owners and intentions of the designer, they are referred to as the regulation value, limit value and target value, respectively, in the Recommendation.

When considering the environmental performance by comparative design, the designer is not necessarily required to set a target value, and "verification" will become unnecessary if the decision-maker selects an appropriate one from the environmental performance evaluation results of several designs.

In the design of concrete structures, safety, serviceability and durability have been verified. In the future, the consideration of environmentality will become necessary in addition to these. It is, however, obvious that environmentality is essentially different from safety etc. This means that, in case of design for safety, a structure is required not to cause direct damage to people or society by its destruction. As for environmentality, no reasonable systems have been established for the control of greenhouse gases, air contaminants, resources/energy and waste, although direct contamination and noise have been taken into account under legal regulations. This is because the final damage of global environment issues is yet to be clarified. Although it is easy to imagine that various substances generated as a result of human activities will eventually cause damage to humans, society and ecosystems, the problem is that it is difficult to evaluate these damages quantitatively. It is, however, necessary to prevent further aggravation of the situation by not taking any measures merely because of the lack of clarity regarding these damages.

The Recommendation of Environmental Performance Verification for Concrete Structures (draft) presented here was developed based on the idea that systems to enable reduction of environmental impacts should be established in a variety of concrete-related activities. While this Recommendation (draft) is based on the performance verification system of the JSCE Standard Specifications for Concrete structures, it can also be used for comparative design related to environmental performance or environmental labels/declarations of ISO.

4.2. Application of the JSCE Recommendation [23]

An example of the application of the JSCE recommendation is described as follows:

1) General

There is a plan to renew reinforced concrete pedestrian bridge across a river. Considering the span of the bridge, approximately 50 m, a three-span prestressed concrete bridge is conventionally one option. However, according to the required performance regarding environmental impact reduction, a new technology needs to be introduced.

2) Environmental performance requirement

A 20% reduction of CO_2 emission in the construction of the pedestrian bridge was required compared with conventional structure as an environmental performance requirement.

3) Solution

Ultra high-strength steel fiber-reinforced concrete (UFC) can dramatically reduce the dead weight of a structure because of its excellent strength characteristics. The foundation can be thinner as a result and may also lead to the reduction of construction costs. The maintenance cost can also be reduced because of the excellent durability of UFC. Table 5 and Figure 14 show the mix proportions and the bending behaviour of UFC. Steel fiber of 0.2 mm in diameter, 15 mm in length and 2800 N/mm^2 in tensile strength was mixed. UFC was used to construct a 50.2-meter-long 2.4-meter-wide outer-cable prestressed bridge with an un-reinforced box-type closed section with variable web height (upper slab thickness = 5 cm, web thickness = 8 cm). Figure 15 and 16 show the general view and cross section of this bridge, respectively. The dead weight of the bridge was 560 kN. Precast blocks consisting of three types of segment blocks were manufactured at a precast concrete product plant. They were cured twice. Sheet curing was first conducted in an open-air environment, followed by a 48-hour steam curing at 90°C. If this bridge was to be designed as a three-span, PC simple slab bridge (hereinafter referred to simply as "PC bridge"), which is thought to be the most rational for its conditions, its dead weight would be 2,780 kN, approximately 5 times that of the UFC bridge. Figure 17 shows a general view of the hypothetical PC bridge.

4) CO_2 Emission of UFC pedestrian bridge and verification

The CO_2 emissions from the production of the mate-

Table 5.
Mix proportions of UFC

Water	Cement	Grain (quartz, sand, etc.)	Steel fibers	Super-plasticizer
180	818	1479	157	24
Unit: kg/m^3, the water includes water content in superplasticizer, 19 kg/m^3				

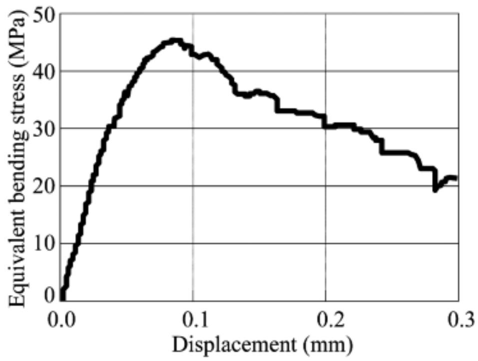

Figure 14.
Flexural behaviour of ultra high-strength steel-fiber reinforced concrete

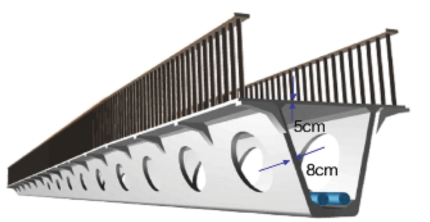

Figure 15.
Sectional view of UFC bridge

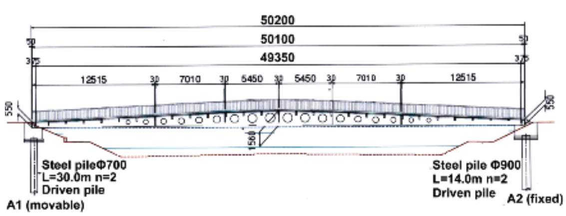

Figure 16.
General view of UFC bridge

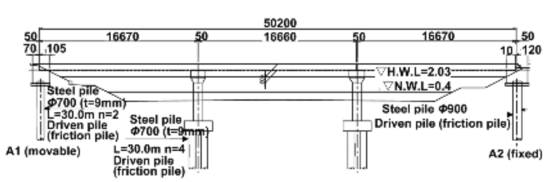

Figure 17.
General view of hypothetical PC bridge

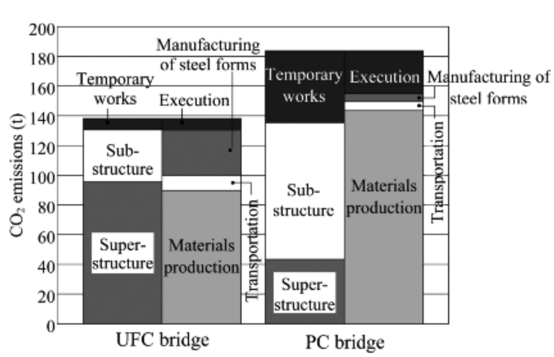

Figure 18.
CO_2 emissions of UFC and PC bridges

rials, steel forms, and UFC beams or pre-tension hollow beams, the transport and construction were calculated for UFC and PC bridges. Figure 18 shows the results. By utilizing UFC, CO_2 emissions could be reduced by approximately 25% in all, compared with a conventional PC bridge. The environmental requirement was verified, i.e. the environmental performance requirement regarding CO_2, S, was less than the retained performance, R. For the calculation of CO_2 emission, the JSCE unit-based substance emission data base [4] was used.

5. CONCLUDING REMARKS

The IPCC (Intergovernmental Panel on Climate Change) adopted the Fourth Assessment Report, which integrated Assessment Reports that had been published successively by three Working Groups since the beginning of 2007. In the Fourth Report, it is clearly stated that global warming was induced by human activities. It is reported that the average global temperatures could rise by up to 6.4 degrees Celsius by the end of this century and that in order to limit temperature rise to 2 to 3 degrees Celsius, greenhouse gas emissions must be halved by 2050. As shown by the IPCC and Al Gore, the former Vice President of the United States who directed a movie titled “An Inconvenient Truth”, having jointly won the Nobel Peace Prize in 2007, global warming has become the most important political issue in the world. We must say that the amount of greenhouse gas emission reductions from 1990 levels required under the Kyoto Protocol means virtually nothing, but it was an important decision that marked the beginning of the reduction of greenhouse gas emissions.

The current status of social infrastructure development is diversified in the world. Among developed countries, infrastructure development has reached maturity and its maintenance and operation are increasingly important, whereas the current status is different among developing countries, ranging from countries that have already begun building basic infrastructure for economic development to those that need to start construction of entire infrastructures from now. However, when we look at the situation from a long-term perspective, developed countries will need to update their infrastructures in the future. In this way, it is obvious that a tremendous amount of resources and energy is required for the improvement of infrastructures worldwide.

Therefore, the infrastructure quality needs to be improved from an environmental point of view from now on. In this regard, an "environmental-benefit" evaluation of infrastructure construction is essential. How environmental benefit is integrated into environmental standards as an ISO system to reduce environmental burdens is a major challenge for the future.

As the IPCC points out, if a 50% reduction of greenhouse gas is set as the target for 2050, what kind of strategy should the construction sector take to respond to the target? It is natural that the amount of greenhouse gas emission reductions is different among each industry. Yet, it does not mean the construction industry will be given permission to do nothing, and it is unreasonable to force only the material industry, such as the steel or cement industry, to bear the burdens. It is essential to promote technical innovations concerning structure, construction, maintenance & operation, demolition and recycling in addition to the manufacturing of materials. To this end, the construction industry needs to continue concrete actions as it creates new approaches to reduce environmental burdens in all fields related to construction. Although the construction sector has basically been considered to be a local industry, it needs to develop from a global environmental point of view from now on.

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