THE ROLE OF THE CONCRETE SECTOR CONCERNING SUSTAINABILITY

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ABSTRACT: This paper describes the role of the concrete sector concerning sustainability, considering the environmental impacts from the activities by the concrete sector and its reduction scenarios. It is concluded that in order to comply with the low carbon society that mankind aims for in the 21st century, the concrete sector must endeavor to develop appropriate innovative technologies. We are now on the very starting line.

Introduction

According to Earth and planetary physics, it can be assumed that the Earth is about 4.5 billion years old. Following collisions with numerous planetoids, it became the current size and differentiated into its principal constituents; core, mantle, crust, ocean and atmosphere. The concrete sector uses an enormous amount of various rocks, the most bountiful resources which comprise the Earth’s crust, for aggregates and cement materials.

It has been revealed by the recent advanced research of genetic information that the contemporary human based on the anatomical definition, began migrating throughout the world from Africa approximately 50,000 years ago. An amazing yet rational idea has shown that during their migration, their skin color and features changed to adapt to the environment. It was a mere 10,000 years ago when an agrarian society in a form that we can call civilization was developed, while as for city-states, it was only 5,000 years ago. The Roman Empire ruled the Mediterranean and European regions for a period of one thousand years that extended from before and following the birth of Christ. Then, following Middle Ages over another millennium and the rise and fall of dependent territories during Roman Ages, we saw the advent of the Industrial Revolution in Great Britain, and entered the era of Pax Britannica. During these years, although environmental problems did occur in the form of the destruction of nature, they were in retrospect tolerable on the global scale. Nevertheless, since mass production and mass consumption were made possible by this Industrial Revolution, which began in the mid-18th century, humankind simply marched forward until today, spending resources and energy based on the principle of an economic society. This has

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resulted in a global-scale crisis which we never even imagined.

The Earth’s atmosphere presently consists mainly of nitrogen and oxygen in about 80% and 20% respectively, with very little carbon dioxide. However, while only 280 ppm of carbon dioxide existed before the Industrial Revolution, it now exceeds 380 ppm due to the combustion of fossil fuel. It is known that carbon dioxide in the atmosphere is an extremely important gas in terms of maintaining a mild climate on the Earth, but it has now increased to the extent that it is causing global warming due to the production of a rising number of industrial products owing to the recent drastic population increase. The Intergovernmental Panel on Climate Change (IPCC) warned in their Fourth Assessment Report that global warming has already begun due to human activities, and thus it is necessary to reduce CO₂ concentration by 85-50% from the year 2000 levels by 2050, in order to maintain it at a level of 350-400 ppm. However, even if this is achieved, a temperature increase of 2.0-2.4°C is unavoidable. If the CO₂ concentration increases by 90-140% from the 2000 levels by 2050, the temperature is expected to rise by 4.9-6.1°C, resulting in thermal expansion of the oceans. This alone will cause a global average sea level rise of 1.0-3.7 m compared to that of before the Industrial Revolution. These predictions demonstrate that humankind is facing an extremely serious situation. The least bad thing is that we have acknowledged the necessity to seriously address these problems, and have begun taking concrete action.

During the L'Aquila G8 Summit held in June 2009 in Italy, it was agreed that the developed countries reduce greenhouse gas emissions by 80% by 2050. Despite fierce arguments between the developed and developing nations concerning emissions reduction targets and economic development, the Major Economies Forum (MEF) explicitly stated in its leaders’ communiqué that the increase in global average temperature above pre-industrial levels should not exceed 2°C. This actually means that they indirectly stated that greenhouse gas emissions from the whole Earth should be reduced by around 80% by 2050. Future tasks therefore lie in how to share such reduction targets between the developed and developing nations. After more than ten years since the Kyoto Protocol stipulated in 1997 that the developed countries should reduce the emission of greenhouse gases by approximately 5% compared to the year 1990 levels by 2013, we have finally reached the core of this problem.

This is how the combating action concerning greenhouse gas reduction has got on track. A large number of industries have already moved forward in this direction. It is obviously meaningless for the concrete sector to go against this trend. However there remain a great many differing degrees in attitude toward this issue within the sector. This is due perhaps to a lack of common understanding regarding where the sector stands in terms of CO₂ emissions and what specifically should be done.

With the intension of getting out of this situation, the paper first studies the nature of the controversy concerning this problem in the concrete sector, and then discusses what the role of the concrete sector is with respect to our goal of a sustainable future, while presenting the status of the sector’s CO₂ emissions as well...
as examples of low carbon concrete technology which relate to reduction scenarios.

Controversy on sustainability in the concrete sector

Prof. Mehta\(^3\) expresses his opinion concerning the scenario to reduce CO\(_2\) emissions caused by cement to half or less by 2030. His basic concepts involve using the following three tools as shown in Figure 1.

- Tool 1: Consume less concrete for new structures
- Tool 2: Consume less cement in concrete mixtures
- Tool 3: Consume less clinker in cement

![Figure 1: Sustainability tools by Mehta\(^3\)](image)

Regarding Tool 1, he states that we must continue to develop innovative architectural concepts and structural designs for new construction and the rehabilitation of old structures. As one example of Tool 2, he says that instead of a 28-day compressive strength, we should specify a 56- or 90-day compressive strength in structural elements whenever possible because a large volume of concrete is consumed for the construction of foundations, columns, beams, and structural walls that are seldom subjected to significant structural loads before two to three months of age. As for Tool 3, he asserts that blended Portland cements and concrete mixtures that contain a high volume of one or more cementitious materials such as fly ash, slag cement, natural or calcined pozzolans, silica fume, and reactive rice-husk ash reduce the amount of Portland cement needed to produce concrete.

With respect to this paper, Aris Papadopoulos\(^4\) pointed out that judicious use of
materials does not necessarily mean minimal, but optimal life-cycle use, and becoming more sustainable by consuming less concrete, cement, clinker, or any material for that matter is oversimplifying the global sustainability challenge. He concluded that industry and society will benefit if academics and practitioners alike focus more on developing an integrated system, rather than component solutions, to the important issues we face. Of course, Prof. Mehta objected to this and concluded that in the era of global warming, unrestricted growth of heavy carbon-emitting sectors of the economy is bound to be a target of public scrutiny and control.

This argument clearly reveals the nature of the concrete sector’s controversy. Prof. Mehta simply insists that we should consume less concrete, cement and clinker, in order to reduce CO$_2$ emissions, while Aris Papadopoulos says that judicious use of materials does not necessarily mean minimal, but optimal life-cycle use. The author thinks that both points are correct but not sufficient. In other words, both their thinking is based on different prerequisites concerning the controversy. Aris Papadopoulos says that it is appropriate for the use of concrete to take the life of concrete structures into consideration and optimize the reduction of environmental load. This opinion is correct in general terms. However the life of concrete structures is generally assumed to be 50 to 100 years, while the IPCC is talking about the reduction of CO$_2$ emissions over a time span of approx. 40 years from now to 2050. This means that the greater longevity of new concrete buildings cannot contribute to CO$_2$ reduction by 2050. Naturally, extending the life of existing concrete structures will result in contributing to CO$_2$ reduction as the demand for concrete decreases. What is needed though is to drastically reduce CO$_2$ emissions from the concrete sector within decades. It is unknown what Aris Papadopoulos means by ‘an integrated system’, but at least it appears to include some measures other than the reduction of component materials. On the other hand, Prof. Mehta strongly urges reducing the consumption of concrete and clinker through the use of supplementary cementing materials. He proposes as an example, the use of the high volume fly ash concrete which he developed. However, as both the production areas and volume of blast furnace slag and fly ash are limited, we have to realize that there is a limit to their use. In addition, many uncertain elements remain concerning their future production volume.

Based on the above argument, the issues are summarized as follows: In view of the concept of sustainability, it is a basic principle also for the concrete sector to secure required performance through the use of minimum resources and energy as much as possible. It is meaningless to argue against this principle at this stage, and it is required based on the basic principle, to rationalize the extraction of resources, manufacture of materials and the design, execution, and use of concrete structures. Further, all concrete structures are ultimately demolished by a multiple of factors, and their recycling will be needed. During the course of all these steps, CO$_2$ will be emitted. Particularly under the present technology, the manufacture of cement generates a significant amount of CO$_2$. I believe that there is no objection to the fact that the concrete sector should focus on the development of technology to reduce CO$_2$ emission from every point of view, by comprehending the current situation as clearly as possible, and accurately predicting the future concrete production.
The author has carried out detailed discussions concerning the CO$_2$ reduction scenarios for the concrete sector$^3$, 6), 7). The following is a compilation of those discussions, with additions and revisions.

**CO$_2$ emission from concrete sector**

Concrete is the most important construction material and is also used in the largest amounts. Although there are no international statistics concerning concrete usage, on the assumption that cement produced in 2008 (2.83 billion tons) was used entirely for concrete, and that 7.7 tons of concrete can be produced with one ton of cement, the concrete production for the year is estimated at approximately 21.8 billion tons (the actual value is smaller, since cement is also used as other construction and soil amendment materials). Since the global population is approximately 6.6 billion, this figure corresponds to a consumption level of approximately 3.3 tons per person. It can therefore be seen that concrete is the second most-used material on earth after water.

The largest source of concrete-related CO$_2$ emissions is cement. Figure 2$^8$ shows world cement production by region and main countries. Using the average unit-based CO$_2$ emission value for cement (0.87kg of CO$_2$ per kg of cement) means that 2.46 billion tons of cement-originated CO$_2$ was emitted during 2008. Half of the emission was from China. Figure 3 shows the estimated cement demand presented in a report published by the World Business Council for Sustainable Development in 2002$^9$. Production in 2008 corresponds to the highest predicted scenario.
On the assumption that cement consumption per person will double and the population will reach nine billion in the future, world cement production is expected to reach 7.72 billion tons. This means that approximately 6.71 billion tons of cement-originated CO$_2$ will be emitted. The magnitude of its impact can be understood by considering that the total of CO$_2$-equivalent greenhouse gas emissions in 2005 was 27.1 billion tons.

Aggregate accounts for 70% of the volume of concrete. It is said that, out of the annual material flow of 26 billion tons in the world, approximately 20 billion tons
are used for aggregate as a construction material\textsuperscript{(10)}. Using the unit-based CO\textsubscript{2} emission value from aggregate production/transportation (8.1kg of CO\textsubscript{2} per ton of aggregate), according to the author’s study in Japan, CO\textsubscript{2} emissions from aggregate is estimated to be 160 million tons, which is relatively small.

Water is essential in concrete production. Considering that the unit water content of concrete is 0.17 tons/m\textsuperscript{3}, 1.5 billion tons of water is used. However, CO\textsubscript{2} emissions stemming from water usage are generally very small.

Concrete is usually produced by mixing its components after transporting them to a plant, and is then transported to construction sites. Light oil and electricity are used in these processes, accounting for around 25\% of the CO\textsubscript{2} emitted overall in cement production according to studies conducted by the author in Japan. CO\textsubscript{2} emissions from these sources are thus estimated to be 820 million tons. While this value naturally varies greatly according to the prevailing conditions, it is presumed that the global average is actually much higher.

Most concrete is reinforced, meaning that CO\textsubscript{2} from the production of the steel is added. In Japan this is almost 100\% electric-furnace steel, of which 10 million tons is produced with CO\textsubscript{2} emissions of 7.67 million tons. Considering the cement production of 50 million tons in Japan, this means that approximately 0.15 tons of reinforcement-originated CO\textsubscript{2} is emitted per ton of cement. When blast-furnace steel is used, the value becomes more than double. For the cement production level of 2.83 billion tons in 2008, CO\textsubscript{2} emissions originating from electric-furnace steel production were estimated to be 425 million tons. The CO\textsubscript{2} emitted in transporting the steel is ignored here.

In the development of infrastructures, the other steel than reinforcing bars is used. If it is assumed that 30\% of steel production is used for that. The total CO\textsubscript{2} emission from steel production is 850 million tons. The Japanese unit-based CO\textsubscript{2} emission value for blast furnace steel production (2.175t-CO\textsubscript{2}/t), which is the lowest value all over the world, was used for the calculation.

The total amount of CO\textsubscript{2} emitted is therefore estimated to be approximately 4.71 billion tons. In addition, CO\textsubscript{2} emission from execution is 1.17 billion tons based on author’s investigation in which 20\% of all CO\textsubscript{2} emissions come from execution. The CO\textsubscript{2} emissions from the demolition-related activities of concrete structures are ignored because of the lack of data. Therefore, the total amount of CO\textsubscript{2} emissions from all activities as concrete sector becomes approximately 5.8 billion tons. If the CO\textsubscript{2} amount doubles in the future, it means 11.6 billion tons of CO\textsubscript{2} emissions. It corresponds to 39\% of the world 2007 CO\textsubscript{2} emissions from oil-origin, 30 billion tons. If the clinker factor of cement, 0.85, is considered, it is 35\%.
CO₂ Reduction scenarios in concrete sector

Scenario A

In 2007, the IPCC published a report on carbon capture and storage (CCS)\(^1\) – a technology to collect CO₂ emitted from power plants and factories and store it underground. The fourth report of the IPCC\(^2\) recommends the introduction of CCS technology to the energy, cement and steel industries as examples of sectoral mitigation technologies. The technology requires the separation of CO₂ from combustion exhaust gas and injection into a deep layer of ground, it poses problems in terms of the environmental risk associated with its effects on groundwater and stability of storage, in addition to the issue of CO₂ separation costs. It will therefore be a considerable time before this technology is widely used. Furthermore, if we place unrealistic expectations on this technology, it may end up becoming a hindrance to the development of other innovative technologies to reduce CO₂ emissions. Considering the current situation, the idea of introducing CCS technology to the cement production sector is not practically realistic.

Scenario B

Cement is produced by the calcinations of limestone (80%) and clay (20%) in a kiln at around 1,450°C. Cement production therefore generates large amounts of CO₂. In general, CO₂ from cement production is emitted almost 50:50 from fossil fuels and the decarbonisation of raw materials. It is therefore necessary to consider the introduction of efficient fossil fuel combustion technologies and a composition of materials that allows a reduction of the calcination temperature in order to lower CO₂ emissions from cement production.

In the area of fuel combustion technologies, the use of waste heat from kilns and improvements in heat exchange efficiency can be considered. Energy saving in clinker crushing, combustion burners and other facilities is also important. Figure 4 shows an international comparison of energy consumption per ton of clinker (percentage compared with Japan as a base value of 100); there is plenty of room for CO₂ reduction. The fluidized bed cement kiln system was developed in Japan as a new cement production technology\(^3\) that reduces CO₂ by 10 to 25% compared with rotary kilns under certain conditions. NOx emissions can also be reduced by more than 40%. This technology is characterized by an autogenous hot granulation system and high energy efficiency stemming from the use of a fluidized bed. It is effective to introduce the technology at the time of cement plant establishment or renewal. However, if the size of a plant becomes larger, the CO₂ reduction effect lowers. Because of that reason, there is no application in Japan so far.

Industrial waste is currently used in large amounts as a raw material and as fuel in cement production. Figure 5 shows the yearly changes in cement production and industrial waste usage in Japan. It can also be said that the cement industry
processes large amounts of industrial waste. While CO₂ is naturally emitted by the combustion of such waste, the question is whether to count it as part of the CO₂ emitted from cement production. Figure 6 presents an international comparison of the unit-based CO₂ emissions from cement production. These data probably do not include the CO₂ emitted from waste utilization. It will be necessary to establish rational rules in the future.

The use of biomass fuel in cement production has recently attracted attention. Although it is appealing as it can be handled as carbon neutral, there are a variety of restrictions concerning its acquisition. For carbon neutralization, CO₂ absorption by the carbonization of concrete from demolition is also considered possible. However, detailed studies of its effects will be necessary in the future.

The development of new cement systems has been promoted from the viewpoint of reducing CO₂ emissions and energy consumption. As one such system, sulfoaluminate clinker consisting of limestone, bauxite and sulfate calcium is being considered. This clinker is produced at the temperature of 1259-1300°. However, it will be necessary to solve its performance- and cost-related problems before it is widely used. This study indicates the possibility of replacing conventional Portland cement with a cement system that has a low CO₂ impact.

Figure 4: International comparisons of energy consumption in cement-clinker production⁹)
**Figure 5:** Utilization of waste in cement manufacture in Japan\textsuperscript{14}

**Figure 6:** International comparisons of unit-based CO\textsubscript{2} emissions in cement-clinker production\textsuperscript{9}

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*16ο Συνέδριο Σκυροδέματος, ΤΕΕ, ΕΤΕΚ, 21-23/10/2009, Πάφος, Κύπρος*
Scenario C

Blast-furnace slag, fly ash and other industrial byproducts have been used as additions for concrete. These materials function as partial substitutes for cement. This therefore means that their use in place of cement can reduce overall CO$_2$ emissions, which has recently attracted attention from an environmental viewpoint. Global crude steel production in 2007 was 1.34 billion tons$^{15}$, meaning that approximately 389 million tons (1.34 billion tons×0.29 = 0.389 billion tons) of blast-furnace slag was produced. Substituting this for cement produced in 2008 (2.83 billion tons) would reduce cement use by approximately 14%, representing a CO$_2$ reduction of 344 million tons (24.6× 0.14). Meanwhile, world coal-fired thermal power generation in 2005 was 7,350,724 GWh$^{16}$. According to the survey in Japan, coal fly ash of 0.03525 kg is generated per kWh of power, of which about 40% is thought to be used as a substitute for cement. The amount of fly ash that could be used globally is therefore estimated to about 96 million tons. If world cement production in 2008 (2.83 billion tons) is substituted with this, cement use can be reduced by approximately 3.39%, representing a CO$_2$ reduction of 98 million tons (24.6×0.0399). It should be noted that even if twice as much as fly ash can be used, the amount of CO$_2$ reduction from fly ash replacement in cement is only 200 million tons.

While the environmental impacts of blast-furnace cement and fly ash themselves do not include those associated with their production (since they are formed as industrial byproducts), they may greatly affect the motivation for their use. This is because the disposal of these materials becomes a serious problem if they are not used efficiently, and their use can be a great advantage for those who discharge them.

The author examined the environmental impact reduction effects of chemical admixtures to explore the possible contribution of using them in reducing environmental impacts. While the purposes of adopting air-entraining (AE) or high-range AE water-reducing agents include improving workability and durability, the effects on the mix include the reduction of unit water content and a subsequent decrease in unit cement content. Total CO$_2$ emissions from the production of concrete components using AE and high-range AE water-reducing agents were therefore calculated, and the environmental impact reduction effect was estimated. It was assumed that the average unit cement content of ready-mixed concrete was approximately 360kg/m$^3$, the unit water content of concrete using an AE water-reducing agent was 180kg/m$^3$, and the water-cement ratio was 0.5. Table 1 shows the mix proportions and CO$_2$ emissions. It can be seen that the amount of cement and CO$_2$ emissions were reduced by approximately 14.6kg/m$^3$ and 5.6% respectively by switching from AE to a high-range AE water-reducing agent. On the assumption that high-range AE water-reducing agents are used for all concrete, the total reduction in CO$_2$ emissions of cement-related origin becomes 138 million tons (24.6 × 0.056).

Table 1: Reduction effect from the use of chemical admixtures
<table>
<thead>
<tr>
<th>Type of concrete</th>
<th>W/C (%)</th>
<th>s/a (%)</th>
<th>Unit content (kg/m$^3$)</th>
<th>CO$_2$ reduction from conversion to high range</th>
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<tr>
<td>AE water-reducing agent</td>
<td>50</td>
<td>46.6</td>
<td>360 (276.0)</td>
<td>14.6 kg-CO$_2$/m$^3$</td>
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<td></td>
<td></td>
<td></td>
<td>801 (3.0)</td>
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<td>935 (2.7)</td>
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<td></td>
<td></td>
<td></td>
<td>0.93 (0.1)</td>
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<tr>
<td>High-range AE water-reducing agent</td>
<td>50</td>
<td>47.8</td>
<td>340 (260.6)</td>
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<td></td>
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<td>842 (3.1)</td>
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<td>935 (2.7)</td>
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<td>3.5 (0.8)</td>
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While it is desirable to promote the use of mineral admixtures and high-range AE water-reducing agents, it is important to confirm the CO$_2$ reduction effect by clarifying the conditions of their use in advance.

**Scenario D**

In Scenarios A to C, the CO$_2$ reduction effects were examined mainly from the materials’ viewpoint. The construction of concrete structures also involves the use of resources and energy. When considering the reduction of environmental impacts in the construction of concrete structures, it is therefore necessary to examine a wide range of factors at the design stage. For materials, one way is to explore the advantages of using high-performance materials. It is also possible to establish new structural forms through technical development or consider composite structures. The author$^{17}$ have discussed some examples on advanced low carbon concrete technologies, in which 25-28% of CO$_2$ reduction was realized by introducing new technologies.

In construction, the environmental impacts depend on the execution methods and the kind of construction machinery. Therefore, it is important to select low-impact ones. In a study that the author conducted on the environmental benefits in the construction of a reinforced concrete underpass, the CO$_2$ emissions associated with the execution were more than 20% of the total, as shown in Figure 7$^{18}$. In other words, the selection of the execution methods greatly affects CO$_2$ emissions. The scenario optimizing the materials, executions and structure is therefore extremely important in reducing the amount of CO$_2$ emitted in construction works.
Portfolio
As discussed above, the concrete sector already has several effective element technologies for CO\textsubscript{2} reduction. Considerable reduction can be achieved by combining these technologies as a portfolio. This means it will be possible to reduce CO\textsubscript{2} emissions by 20–30\%. To reduce CO\textsubscript{2} emissions more than this, further innovation in cement production technologies, execution methods and structural forms will be necessary. Figure 8\textsuperscript{19)} shows the CO\textsubscript{2} reduction potential in the world cement industry. The possible reduction is approximately 18\% of the CO\textsubscript{2} emission from the world cement production. It is interesting to compare this with the above discussions by the author.

![Figure 7: CO\textsubscript{2} emissions from construction of an RC underpass\textsuperscript{18)}](image1)

![Figure 8: CO\textsubscript{2} reduction potential in cement industry\textsuperscript{19)}](image2)
A system to promote the reduction of CO\textsubscript{2} emission from concrete sector

In order to reduce environmental impacts continuously and effectively, we need to introduce some rules for evaluating the impacts appropriately and systems for promoting the reduction of environmental impacts.

As a well-known ISO environmental standard, the ISO 14000 series exist. These standards, which provide basic rules for presenting environmental product labels or declarations or for carrying out LCA, were developed by the ISO/TC207 (Environmental management). In the ISO/TC59 (Building construction), SC14 (Design life) and SC17 (Sustainability in building construction) have also published ISO 15686-6 (Buildings and constructed assets – Service life planning – Part 6: Procedures for considering environmental impacts) and ISO 21930 (Sustainability in building construction – Environmental declaration of building products), respectively. The former presents procedures for the assessment of environmental burdens, while the latter provides rules for the implementation of environmental declarations for building products. However, since both contain only comprehensive information, problems will arise if, for example, the concrete sector tries to carry out practical tasks based on them. The concrete/construction sector, which uses considerable amounts of resources and energy, must therefore have its own environmental standards in order to implement assessment of the environmental impacts imposed by construction projects and reduce such impacts continuously. The ISO/TC71 (Concrete, reinforced concrete, and prestressed concrete) thus decided on the establishment of SC8 (EMCC: Environmental management for concrete and concrete structures) at its 14th Plenary Meeting held in Salvador, Brazil, in 2007. The subcommittee was officially approved at the TMB meeting in February 2008. The ISO/TC71/SC8 has decided to develop the following ISO standards:

Part 1: General principles
Part 2: System boundary and inventory data
Part 3: Constituents and concrete production
Part 4: Environmental design of concrete structures
Part 5: Execution of concrete structures
Part 6: Use of concrete structures
Part 7: End of life phase including recycling of concrete structures
Part 8: Labels and declarations

Part 1 is now being drafted. The EMCC standards will provide a platform and a set of common rules for the evaluation of environmental impacts and benefits of concrete and concrete structures in an objective and transparent manner.
Role of the Concrete Sector concerning Sustainability

The development of infrastructures is an action which secures the core of human activity i.e. the social and economic base. It is doubtful whether the real significance of infrastructure is duly understood by the majority of people who live in a society where the infrastructures are taken for granted. This is in part the responsibility of the construction industry, because we have neglected to make efforts in correctly acknowledging the meaning of our own role and explaining it to society. This is due to the ordering system of this industry. All that contractors are required to do is simply fulfill the owners’ requirements, and owners have not fully ensured their accountability to society, either. This differs greatly from the domestic appliance and automotive industries, where no business can be achieved if they fail to provide good information about their products to the general public.

It is articulated in this paper why the concrete sector cannot avoid the issue on global warming. It is impossible for the sector which emits a significant amount of CO\(_2\), to walk away from the issue and carry on its activities, while the world is heading towards ‘being green’. The present situation should rather be regarded as an unrepeatable opportunity to change the sector’s character to that of actively aiming to ‘be green’, by casting off its conventional conservative values. To achieve this, it is essential to assign a specific place to environmental performance, in addition to conventional safety, serviceability and durability performances. Although the concrete sector has accumulated an enormous amount of technical information regarding concrete, it seems as if it has technically reached a certain plateau, being unable to find the direction of the next-generation technology. The new key word ‘environmental performance’ will encourage the concrete sector to expand and reform its thinking and provide the germination of innovative technological developments.

It is more than 185 years since modern cement was invented in England. Although concrete technology has dramatically advanced during these years, there remain numerous problems to be solved because of its nature in being a simple material using natural resources. Now, facing this CO\(_2\) issue, the concrete sector appears to be destabilized. However, it can be said with certainty that no material will be found in the future which can replace concrete. In that case, the concrete sector bears a significantly grave responsibility concerning the construction of a sustainable society. As global concrete consumption seems to exceed 15 billion tons, it is obvious that it provides a comfortable environment for living, working and leisure, while it is also true that it emits a large amount of CO\(_2\). The problem is that its consumption is predicted to continue to increase enormously, primarily in developing countries. This is therefore not an issue of developing countries alone but of the entire globe. It is inevitable that the concrete sector is a key player with respect to the task of CO\(_2\) reduction on the global scale, and it should take action towards a sustainable future.
Concluding Remarks

During the United Nations Conference on Environment and Development (Earth Summit) held in Rio de Janeiro in 1992, an approach to Sustainable Development which enables the simultaneous pursuit of environmental preservation and economic development was made explicit, and also the United Nations Framework Convention on Climate Change was adopted. It was back in 1987 when the meaning of Sustainable Development was defined in the Brundtland Report\textsuperscript{20} Not many people probably realized in those days that this problem would become as critically important as it has today. The progress of science and technology was simply supposed to promise mankind a more affluent society. Instead our social economic system, which floats on an ocean of fossil fuels, seems to have caused an unprecedentedly serious problem such as global warming, rather than ensuring Sustainable Development. Currently, although the world’s discussions regarding this issue tend to be diffused due to complicated interests, there are few, except for some global warming deniers, who think that it is good to leave it to nature. The majority of nations are simply playing tug-of-war regarding CO\textsubscript{2} quotas. What we all know is that both industry and individuals will without exception be obliged to make serious CO\textsubscript{2} emission-reduction efforts in the near future.

In order to comply with the low carbon society that mankind aims for in the 21st century, the concrete/construction sector must first clearly recognize the status of its CO\textsubscript{2} emissions under the existing technological system, formulate mid-and-long term CO\textsubscript{2} reduction scenarios, and thereby endeavor to develop appropriate innovative technologies. We are now on the very starting line.
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