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Concrete and Sustainability

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ABSTRACT

The history of mankind can be said to coincide with the history of infrastructure for the socioeconomic activities of human beings. Today, an enormous amount of resources and energy are consumed for infrastructure development. This paper argues first concerning the essence of sustainability for the concrete sector, and then conducts an overview of the current status of the sector's CO_2 emissions, discusses its reduction scenario in relation to the next generation concrete technology, and finally takes a comprehensive look at the construction industry in the global environmental era.

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. It was about five million years ago when the origin of mankind emerged, and about 300,000 years ago that Homo sapiens who used stone implements and fire evolved. It has been revealed by the recent advanced research of genetic information [Nayan Chanda 2008] that the origin of contemporary humankind was born in Africa and began migrating throughout the world approximately 50,000 years ago. 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, and the world population during this period was about 200 million. Then, following the Middle Ages over another millennium and the rise and fall of former dependent territories, we saw the advent of the Industrial Revolution in Great Britain, and entered the era of Pax Britannica. As a result, environmental problems must have occurred locally in the form of the destruction of nature, however, they were in retrospect tolerable on the global scale as the world population as of 1750 was less than 800 million. Nevertheless, since socioeconomic activities based on mass production and mass consumption were made possible by this Industrial Revolution, the world population increased dramatically to 6.8 billion. The consumption of resources and energy due to a more than doubling of the world's population over the last half century has resulted in an unprecedented global-scale crisis.

Since the Intergovernmental Panel on Climate Change (IPCC) reported that global warming has definitely begun and was due to human activities [IPCC 2005], awareness concerning this issue has been growing and international discussions towards its resolution have become vigorous. In addition, the ongoing tag-of-war regarding the greenhouse gas emissions reduction quotas set out in the Kyoto Protocol which expires in 2013, has become fiercer between the developed and developing nations. In any event, changing an energy system that relies heavily on fossil fuels is paramount. Given the economic advancement of developing countries, it is also evident that the depletion of natural resources will continue and become an extremely serious issue in the near future.

Today, an enormous amount of resources and energy are consumed for infrastructure development, while the required technology for such development has also changed greatly over time. The materials used for construction of the infrastructure have, since ancient times, been stone and cement, while modern cement was introduced following the invention of a new manufacturing method by the Englishman Joseph Aspdin, who took out a patent for it. Despite having a history of less than 200 years, its consumption continues to rise because of its excellent performance as a cement-concrete construction material. The use of concrete as a construction material was indeed a reasonable choice, considering the fact that rocks, and limestone and clay, which are the raw materials of cement, are the most bountiful resources which comprise the Earth's crust. However, since it became apparent that CO_2 emission contributes to global warming, the concrete and construction sector has also been unable, just like other industries, to avoid this issue, as it emits a huge amount of CO_2 through the use of limestone and energy during cement production, while concrete structures use various steel materials, the production of which also generates a vast amount of CO_2.

This paper argues first concerning the essence of sustainability for the concrete sector, and then conducts an overview of the current status of the sector's CO_2 emissions, discusses its reduction scenario in relation to the next generation concrete technology, and finally takes a comprehensive look at the construction industry in the global environmental era.

ESSENCE OF SUSTAINABILITY FOR THE CONCRETE SECTOR

Prof. Mehta [P. Kumar Mehta 2009] 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.

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

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 [Aris Papadopoulos 2009] 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.

Because all countries will focus on the promotion of nuclear power generation, increase of solar and wind power generation and the use of other renewable energy, as well as deployment of the Smart Grid (electric power network with automated adjustment system), the construction of coal-fired power stations may decrease in the future. Another concern is the stability of fly-ash quality, which relies on the quality of coal. Steel production will surely increase in the future mainly in developing countries including China and India. Blast furnace slag therefore will increase in quantity, too. However as the production of cement will also rise at the same time, the amount of slag available for the substitution of cement will be limited. Further, such substitutable amount may drastically decrease compared to that of today, depending on the degree of increase in the production of steel and cement. Based on these factors, one should recognize that the use of blast furnace slag or fly ash is not necessarily the key solution as a tool to reduce the use of clinker.

In order for concrete to maintain its major position as a construction material, the concrete sector should clarify the meaning of sustainable concrete. Fundamentally, we have to ensure the performance required of concrete, while minimizing the use of limited natural resources and energy. Such an idea is, in short, bad news for the sector, which is engaged in the business of supplying resources and fuel energy. However, to minimize the use of resources and energy is an impregnable principle, not only because they are limited, but also because the continuous consumption of fuel energy may bring about a collapse of the foundations upon which human survival depends. The pursuit of this principle however means to realize the sophistication of material performance, which includes the promotion of low-carbon. When material performance becomes more sophisticated, its value will naturally be enhanced. This means that the amount used will be less, but that its sale price can be raised. Each material industry will be able to survive by shifting from a quantity-based economy to a quality-based economy. Naturally a high performance concrete consisting of such materials allows the rationalization of structural form.

It is necessary for the concrete sector to rationalize the extraction of resources, manufacture of materials and the design, execution, and use of concrete structures, based on the principle of minimizing the use of resources and energy. Further, all concrete structures are ultimately demolished due to multiple factors, and their recycling will be needed. During the course of all these steps, CO_2 will be emitted. The concrete sector should implement a fundamental review of the vast amount of information regarding concrete technology accumulated in the past from the point of view of CO_2 reduction, while accurately predicting future concrete production volume by precisely comprehending the current situation, thereby pursuing the development of innovative technology to reduce CO_2 emission.

Global warming involves all regions where people live. In general terms, it is most probable that the above mentioned sustainable technology will be realized in developed nations, while developing nations have a greater risk of following the path of the technological evolution that developed nations have taken. In order to prevent this, it will be necessary to transfer the cutting edge low-carbon concrete technology developed by the developed nations to developing nations, however we are confronted with major problems concerning its realization. First, who should be paying the compensation for such high technological value. There is no easy answer to this, but it is required to establish a reasonable system regarding a cap on the emission allowance of the technology transferring party and a cost paid by the receiving party. To be more precise, the key to success will be an appropriate adjustment of the cap on the former party, and a fair amount of burden sharing on the part of the latter party through their self-help efforts.

CO_2 EMISSION AND ITS REDUCTION SCENARIO IN CONCRETE SECTOR

CO_2 Emission

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 1 [CEMBUREAU 2008] 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 2 shows the estimated cement demand presented in a report published by the World Business Council for Sustainable Development in 2002 [Humphrets, K. and Mahasenan, M. 2002]. Production in 2008 corresponds to the highest predicted scenario.

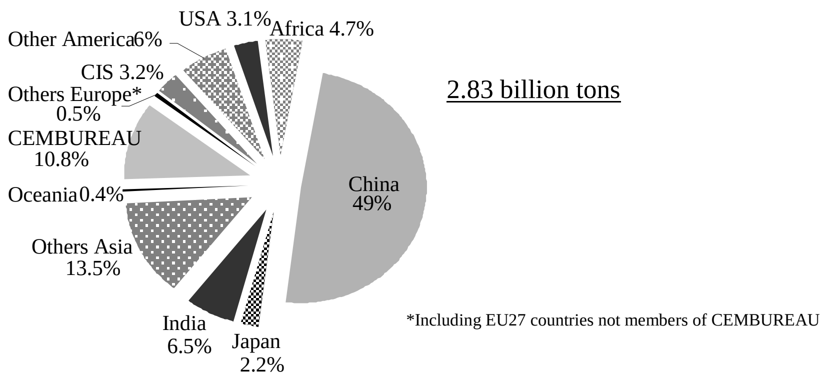

Fig. 1. World cement production by region and main countries (2008)

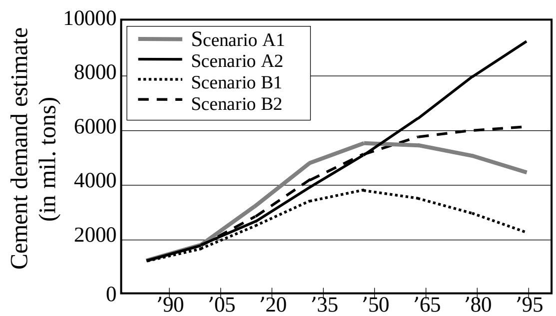

Fig. 2. Estimates of world cement demand

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 [Leser R. Brown 2001]. Using the unit-based CO_2 emission value from aggregate production/transportation (8.1kg of CO_2 per ton of aggregate), according to the author's study in Japan, CO_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^3, 1.5 billion tons of water is used. However, CO_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_2 emitted overall in cement production according to studies conducted by the author in Japan. CO_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_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_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_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_2 emissions originating from electric-furnace steel production were estimated to be 425 million tons. The CO_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_2 emission from steel production is 850 million tons. The Japanese unit-based CO_2 emission value for blast furnace steel production (2.175t-CO_2/t), which is the lowest value all over the world, was used for the calculation.

The total amount of CO_2 emitted is therefore estimated to be approximately 4.71 billion tons. In addition, CO_2 emission from execution is 1.17 billion tons based on author's investigation in which 20% of all CO_2 emissions come from execution. The CO_2 emissions from the demolition-related activities of concrete structures are ignored because of the lack of data. Therefore, the total amount of CO_2 emissions from all activities as concrete sector becomes approximately 5.8 billion tons. If the CO_2 amount doubles in the future, it means 11.6 billion tons of CO_2 emissions. It corresponds to 39% of the world 2007 CO_2 emissions from oil-origin, 30 billion tons. If the clinker factor of cement, o.85, is considered, it is 35%.

CO_2 reduction scenarios

Scenario A: Introduction of carbon capture and storage (CCS) [IPCC 2007], which is a technology to collect CO_2 emitted from power plants and factories and store it underground. The technology requires the separation of CO_2 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 CO_2 separation costs. It will therefore be a considerable time before this technology is widely used. However, if these problems are solved, this technology will be the next generation's technology, although there is a limit to use it.

Scenario B: Development of low carbon cement in terms of the reduction of limestone and calcination temperature. 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 3 [Humphrets, K. and Mahasenan, M. 2002] 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 CO_2 reduction. The fluidized bed cement kiln system was developed in Japan as a new cement production technology [I. Hashimoto and T. Watanabe 1999] that reduces CO_2 by 10 to 25% compared with rotary kilns under certain conditions. Industrial waste is currently used in large amounts as a raw material and as fuel in cement production. Figure 4 [Humphrets, K. and Mahasenan, M. 2002] presents an international comparison of the unit-based CO_2 emissions from cement production. The use of biomass fuel in cement production has recently attracted attention. The development of new cement systems has been promoted from the viewpoint of reducing CO_2 emissions and energy consumption. As one such system, sulfoaluminate clinker consisting of limestone, bauxite and sulfate calcium is being considered [Ellis Gartner and Keith Quillin 2007]. This clinker is produced at the temperature of 1259-1300℃. However, it will be necessary to solve its performance- and cost-related problems.

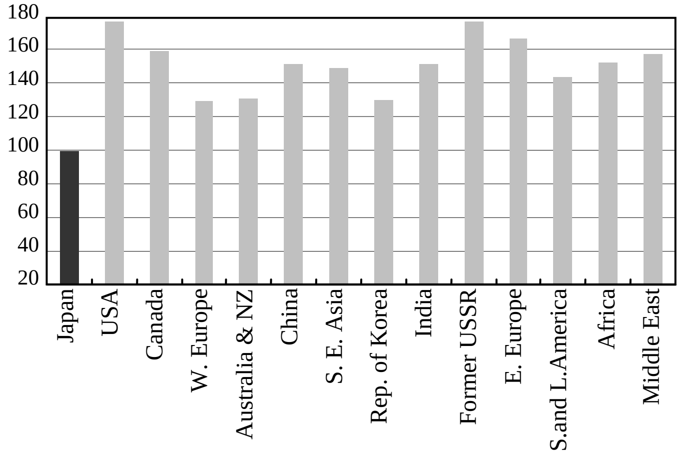

Fig. 3. International comparisons of energy consumption in cement-clinker production

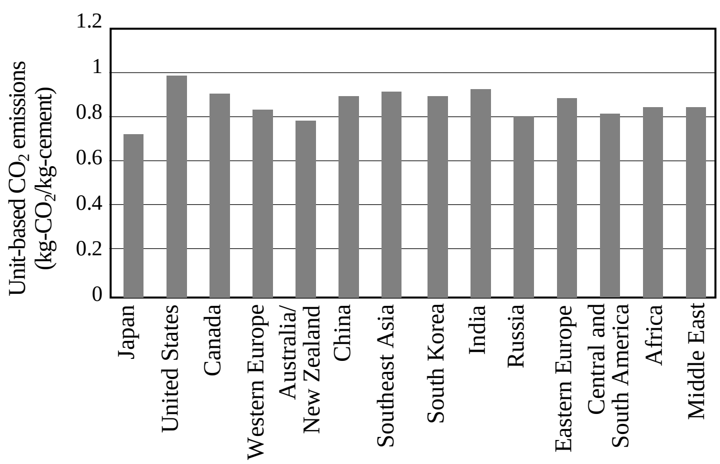

Fig. 4. International comparisons of unit-based CO_2 emissions in cement-clinker production

Scenario C: Use of mineral admixtures, such as blast-furnace slag and fly ash, as additions for concrete and cement replacement and chemical admixtures. Global crude steel production in 2007 was 1.34 billion tons [International Iron and Steel Institute 2008], 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 [International Energy Agency]. 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 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. CO_2 reduction effect from the use of chemical admixtures

Type of concrete	W/C (%)	s/a (%)	Unit content (kg/m^3)／(CO_2 emission (kg-CO_2/m^3))					CO_2 reduction from conversion to high range
			W	C	S	G	Ad	
AE water-reducing agent	50	46.6	180	360 (276.0)	801 (3.0)	935 (2.7)	0.93 (0.1)	14.6 kg-CO_2/m^3
High-range AE water-reducing agent	50	47.8	170	340 (260.6)	842 (3.1)	935 (2.7)	3.5 (0.8)	

Scenario D: Introduction of low carbon design, execution, and demolition methods for concrete structures. It is 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 [Koji Sakai 2005] 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 5 [Koji Sakai 2007]. 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.

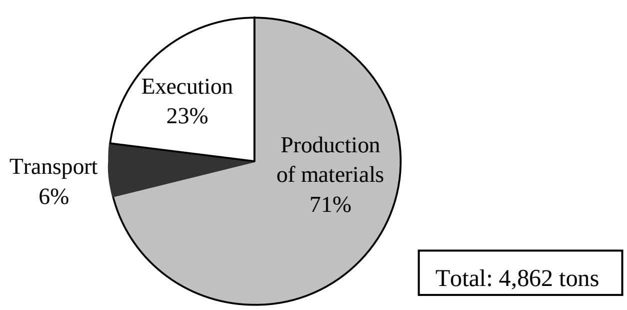

Fig. 5. CO_2 emissions from construction of an RC underpass

Scenario E: Introduction of CO_2 reduction systems. 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 ISO/TC71 (Concrete, reinforced concrete, and prestressed concrete) created SC8 (EMCC: Environmental management for concrete and concrete structures) [Koji Sakai 2008] in 2007. The ISO/TC71/SC8 is now discussing Part 1, general principles. 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.

Portfolio: Combinations of several effective technology tools for CO_2 reduction. The combination of existing tools will make it possible to reduce CO_2 emissions by 20–30%. To reduce CO_2 emissions more than this, further innovation in cement production technologies, execution methods and structural forms will be necessary. Figure 6 [IEA 2008] shows the CO_2 reduction potential in the world cement industry by IEA. The possible reduction is approximately 18% of the CO_2 emission from the world cement production. It is interesting to compare this with the above discussions by the author.

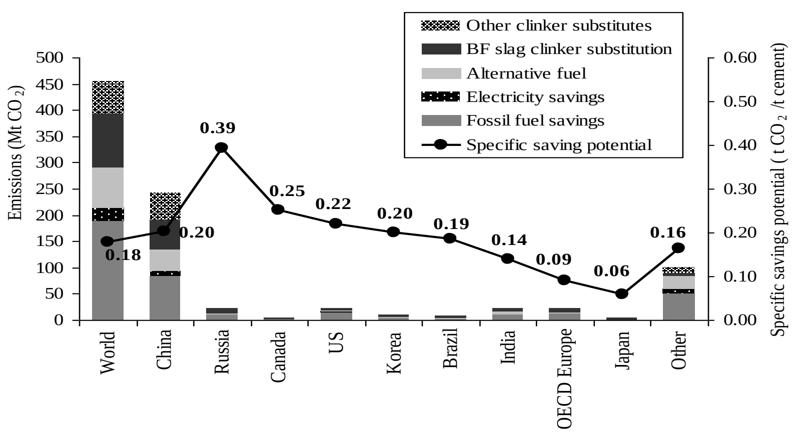

Fig. 6. CO_2 reduction potential in cement industry

ROLE OF THE CONCRETE SECTOR IN THE GLOBAL ENVIRONMENTAL ERA

Global warming will have an immense impact on human socioeconomic activities, and the degree of its impact will depend on how much greenhouse gases humankind will reduce over the next half century. However, according to the IPCC, even if today's highest listed reduction target of 85-50% is achieved, a temperature increase of 2.0-2.4°C is unavoidable, and in the worst case, that is when no countermeasures are taken, 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 1.0-3.7m compared to that of before the Industrial Revolution. Furthermore, with the addition of melting glaciers in Greenland, the sea level will rise even higher.

Under these circumstances, there are two things the construction sector should undertake. One is to reduce to the utmost limit, greenhouse gases arising from the construction sector. Another is to conserve the human living environment and natural environment against abnormal climate and rising sea levels resulting from global warming. These will surely be extremely challenging tasks. The reason is that because of the drastically expanding development of infrastructures among developing nations, and anticipated large number of new facilities constructed to adapt to global warming, one cannot deny the possibility of an increase in the total amount of greenhouse gases generated by the concrete sector, even when it manages to dramatically cut the unit-based emissions. Thus, it is necessary to steadily cut the amount of greenhouse gases as a whole, resulting from the development of infrastructures for socioeconomic activities and from construction for conservation of the human living environment and natural environment. This is the huge task assigned to the construction sector in this global environmental era. As with other industries, it is essential to minimize energy consumption by enhancing resource efficiency.

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 [The World Commission on Environment and Development 1987]. 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.

It is evident that the greenhouse gas concentration has been increasing monotonically, and other scientific information regarding abnormal climate and melting glaciers has been accumulating. Meanwhile, various discussions have been held regarding the simulation results of climate change due to greenhouse gases alone. However, when considering the extreme astral environment of Venus which has a temperature of 450C° resulting from its envelopment in a vast amount of greenhouse gases, or Mars which has an average temperature of minus 55C° resulting from its greenhouse gases having disappeared, one can understand intuitively what is happening on Earth. It is necessary to accept the fact that the world’s scientists have been discussing climate change and issuing critical warnings. Amidst an escalating tug-of-war between developed and developing nations, and industries and government/environment-related organizations, the heart of the issue comes down to how to balance economic growth and environmental cost. Nevertheless, the most important thing is that we who reside on Earth have no choice but to make an effort to drastically reduce greenhouse gases.

This paper discussed the significance of the fact that the concrete and construction sector cannot avoid the issue of global warming, and the comprehensive CO_2 reduction scenario for sustainability in relation to the next generation concrete technology. It is not possible for the concrete and construction sector to walk away from the issue and carry on its activities, while the world is heading towards ‘being green’, and strategically setting such a direction as the core of business development. Rather, the situation should 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. With respect to concrete, the sector should 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 provide the concrete sector with the germination of innovative technological developments.

In order to comply with the low carbon society that mankind aims for in the 21st century, the concrete and construction sector must first clearly recognize the status of its CO_2 emissions under the existing technological system, and formulate mid- and long-term CO_2 reduction scenarios, thereby endeavoring to develop innovative technologies to actualize such scenarios.

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