Committee Report : JCI- TC082A

Technical Committee on Overseas Standards and Requirements for Concrete and Concrete Materials

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Abstract

Materials for concrete reflect regional characteristics in each area of the world and are diverse. Some materials commonly used in Japan may be unfamiliar in other countries. It is difficult to understand the overseas situation only from domestic research activities. Therefore, the Research Committee hosted the International Conference on Construction Materials (ConMat'09) that mainly focused on concrete and its materials, and exchanged information on cutting-edge technologies around the world. In addition, the Committee conducted a questionnaire survey in cooperation with major researchers around the world, and compiled a report on concrete materials that are used in each area of the world.

Keywords: ConMat'09, international research, concrete materials, standards, questionnaire, around the world

1. Introduction

Materials for concrete reflect regional characteristics in each area of the world and are diverse. Some materials commonly used in Japan may be unfamiliar in other countries. Many Japanese engineers work on overseas construction activities based on the concepts of Japanese technologies, but often face differences in attitudes in overseas countries. It is difficult to know the overseas situation only from domestic research activities. Therefore, the International Research Committee hosted the International Conference on Construction Materials (ConMat'09) that mainly focused on concrete and its materials, and exchanged information on cutting-edge technologies around the world. In addition, the Committee conducted a questionnaire survey in cooperation with major researchers around the world, and compiled a report on the concrete materials that are used in each area of the world. The report was presented at ConMat'09 with a proposal on the vision of future concrete materials as the achievement of the Committee.

Table 1: List of Committee members

Chairman	Taketo UOMOTO	Shibaura Institute of Technology
Vice Chairman	Shigemitsu HATANAKA	Mie University
	Keitetsu ROKUGOU	Gifu University
Secretary-General	Yoshinobu NOBUTA	Kajima Corporation, WG1 leader
Secretaries	Kazuo YAMADA	Taiheiyo Cement Corporation, WG2 leader
	Katsunori AYANO	Okayama University
	Keishiro IRIYA	Obayashi Corporation
	Eiji OWAKI	Taisei Corporation
	Toru KAWAI	Shimizu Corporation
	Toshiharu KISHI	Institute of Industrial Science, the University of Tokyo
	Takumi SHIMOMURA	Nagaoka University of Technology
	Takafumi NOGUCHI	The University of Tokyo
	Makoto HISADA	Tohoku University
Members	Keiichi IMAMOTO	Tokyo University of Science
	Akira OHTA	BASF Pozzolith
	Koichi KOBAYASHI	Gifu University
	Mitsuo OZAWA	Gifu University
	Etsuo SAKAI	Tokyo Institute of Technology
	Koji SAKAI	Kagawa University
	Minehiro NISHIYAMA	Kyoto University
	Ippei MARUYAMA	Nagoya University
	Manabu YOSHIMURA	Tokyo Metropolitan University
	Yasuhiro ISHIKAWA	Meijo University
	Shinji KAWABE	Nagoya Institute of Technology
	Minoru KUNIEDA	Nagoya University
	Koji TERANISHI	Meijo University

2. Outline of Committee Activities

The International Research Committee consists of two working groups (WGs). A list of Committee members is shown in **Table 1**.

- ConMat'09 planning working group (WG1): Plans and manages ConMat'09
- International research working group (WG2): Conducts questionnaire survey on concrete materials, technologies and standards, as well as reports the outcome of the survey at the keynote lecture of ConMat'09

2.1 About ConMat'09 (WG1)

The International Conference on Construction Materials (ConMat) is an international conference that discusses a wide range of research and application outcomes of construction materials. The first conference was held in Ottawa, Canada, in 1997, the second in San Jose, the United States, in 2001, and the third in Vancouver, Canada, in 2005. The conferences have been hosted either by Japan or Canada in rotation every four years. Prof. Akthem Al-Manaseer served as chairman of the first conference, Prof. Shigeyoshi Nagataki for the second conference, and Prof. Nemkumar Banthia for the third conference. The fourth conference (ConMat'09, chaired by Prof. Taketo Uomoto, Chairman of the Technical Committee on Overseas Standards and Requirements for Concrete and Concrete Materials) was held in Japan for the first time, and the WG1 of the Committee was involved in reviewing research paper selection, drawing up the presentation program, planning technical exhibitions and tours, etc., and running the conference.

2.2 Questionnaire survey (WG2)

With the help of major researchers around the world, WG2 conducted a questionnaire survey on the concrete materials and related standards in each region, and compiled a report. It also gathered comments on material issues as well as new materials, construction methods and quality assessment technologies, etc., that draw attention in each country. Then, WG2 made a proposal on the future of concrete materials taking all factors into consideration.

The questionnaire was designed placing more emphasis on a comparison of currently-used materials in each country rather than on that of material standards. The questionnaire forms were sent to 55 countries. **Table 2** shows the list of countries which questionnaire forms were sent.

Questionnaire items that covered all concrete materials and design methods were prepared. **Figure 1** shows the basic concept of the questionnaire. The questionnaire items were divided into the categories of materials including cement, aggregate, mineral/chemical admixtures and steel reinforcement as well as those of concrete production, construction and durability design. Each category includes questions concerning statistical data, quality and standards. These questions were saved in an Excel file for distribution. A list of questionnaire items is shown in **Table 3**. In addition, any comments on each questionnaire item were gathered including concerns and new materials, construction methods and quality assessment technologies that draw attention in each country. When no statistical data were available, estimated values based on relative comparison or no responses were accepted to collect as many answers as possible. Furthermore, WG2 asked several persons in Japan to answer the questionnaire to prepare sample answers, and discussed the suitability of questions to improve the questionnaire.

Table 2: List of countries to which questionnaire forms were sent

Asia	**South America**
India	El Salvador
Indonesia	Costa Rica
South Korea	Colombia
Singapore	Panama
Sri Lanka	Paraguay
Thailand	Brazil
China	**Africa**
Japan	Algeria
Nepal	Uganda
Pakistan	Egypt
Bangladesh	Ethiopia
Philippines	Kenya
Vietnam	Zambia
Malaysia	Tanzania
Laos	Tunisia
Middle East	South Africa
Iran	**Europe**
Oman	UK
Saudi Arabia	Italy
Dubai	Netherlands
Turkey	Kosovo
Bahrain	Switzerland
Oceania	Sweden
Australia	Spain
New Zealand	Slovakia
Oceania	Denmark
Republic of Palau	Germany
North America	Norway
United States	France
Canada	Portugal
Mexico	

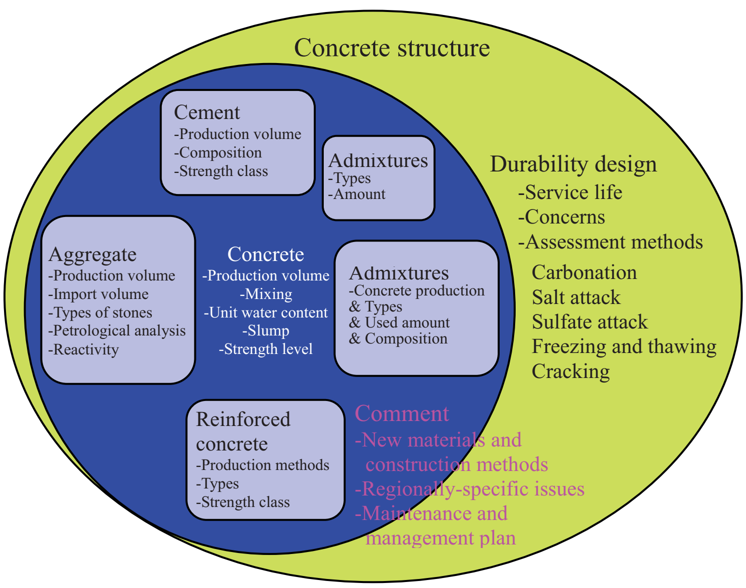

Figure 1: Concept of questionnaire survey

Table 3: List of questionnaire items

Cement	Statistical data	Production volume Consumption volume
	Production plants Price Types of cement Strength class	Number of plants Types of kilns Top four types of cement and breakdown
	Standards	
Aggregate	Statistical data	Consumption volume
	Types of aggregate and breakdown	Crushed stones Natural aggregate Recycled aggregate By-product (slag aggregate) Others
	Quality standards	Density Water absorption rate Others
	Control of grain size	
	Price	
	Petrological analysis	
	Alkali reactivity test	
Mineral/ Chemical Admixtures	Types of chemical admixtures	Water-reducing admixture High-range air-entraining (AE) and water-reducing admixture Others
	Bases	Lignin sulfonate Naphthalenesulfonate Melamine Polycarbonate
	Mineral admixture	Ground granulated blast-furnace slag Fly ash Fine powder of limestone Silica fume Expansive agent Others

Concrete	Statistical data	Production volume
	Production	Mixing methods Transportation Measurement error
	Construction	Placing and Compacting
	Quality	Unit water content Slump Strength level
	High-quality concrete	Self-compacting concrete High-strength concrete
	Price	
Durability	Durability design	
	Design service life	
	Critical review	
	Detection and measures against deterioration	Carbonation Salt damage Drying shrinkage Temperature stress Alkali-silica reaction (ASR) Chemical corrosion Thaumasite sulfate attack Sewer systems Delayed Ettringite Formation(DEF) Freezing and thawing
Steel reinforcement	Statistical data	Production volume Consumption volume Import and export volume
	Production methods	
	Types	Round bar Deformed bar
	Standards	
	Corrosion control measures	

3. 4th International Conference on Construction Materials – Performance, Innovations and Structural Implications (ConMat'09)

The 4th International Conference on Construction Materials – Performance, Innovations and Structural Implications (ConMat'09) - was held at the Nagoya Congress Center in Nagoya, Japan from Monday 24 to Wednesday 26 August 2009. The Conference was organized by the Japan Society of Civil Engineers (JSCE), Japan Concrete Institute (JCI) and Canadian Society for Civil Engineering (CSCE). The conference was a clear success, with 25 countries represented, 344 participants and 221 presentations given. The participants were from a variety of prominent fields including academic institutions, consultants, design and engineering firms, material suppliers and students.

At the opening session on August 24, the participants were welcomed by Prof. Taketo Uomoto (Chair of the Organizing Committee, Shibaura Institute of Technology), Prof. Nemy Banthia (Co-chair of the Organizing Committee, University of British Columbia), Prof. Emeritus Kenji Sakata (President of JCI) and Prof. Toyoaki Miyagawa (Chairman of the Concrete Committee of JSCE).

Table 4: Breakdown of Participants

Registrations			
344 participants from 25 countries			
Belgium	2	Malaysia	3
Canada	9	Norway	1
China	3	Poland	1
Czech Republic	1	Saudi Arabia	1
Finland	2	Singapore	2
France	3	South Africa	1
Germany	2	Sweden	1
India	1	Switzerland	2
Indonesia	1	Taiwan	8
Iran	11	Thailand	4
Italy	3	The Netherlands	4
Japan	233	UK	2
Korea	19		

Photo 1: Welcome speech by the Chair, Prof. Uomoto (left) and Prof. Miyagawa (right)

During the course of the conference, a total of 12 invited and keynote lectures were provided by international leading researchers and engineers shown below.

- INVITED LECTURES -

① Full-scale 3-D shake table tests on reinforced concrete building structures at E-Defense,
Prof. Toshimi Kabeyasawa, The University of Tokyo, JAPAN

② The concrete construction industry in ASEAN-Countries today,
Prof. Ekasit Limsuwan, Chulalongkorn University, THAILAND

③ Structural assessment of concrete structures damaged by fracture of reinforcing steels due to alkali-silica reactions,
Prof. Toyoaki Miyagawa, Kyoto University, JAPAN

④ Design equations for debonding strains in FRP-strengthened concrete structures,
Prof. Kenneth W. Neale, University of Sherbrooke, CANADA

⑤ Non-destructive testing of bridges,
Prof. Herbert Wiggenhauser, BAM - Federal Institute for Materials Research and Testing, GERMANY

⑥ Green projects: Example of a building and a bridge,
Prof. Mahesh Tandon, Tandon Consultants Pvt. Ltd., INDIA


Photo 2: Invited Lectures by Prof. Limsuwan (left) and Prof. Wiggenhauser (right)

- KEYNOTE LECTURES -

① Research activity of JCI Technical Committee TC-075B: Autogenous healing in cementitious materials,
Prof. Shin-Ichi Igarashi, Kanazawa University, JAPAN

② Maintenance for leakage due to cracking in concrete structures,
Prof. Sang Keun Oh, Seoul National University of Technology, KOREA

③ Analysis of Roman Concrete Excavated from the Somma Vesuviana Archeological Site,
Prof. Etsuo Sakai, Tokyo Institute of Technology, JAPAN

④ The current state and future prospects of the environmental performance of concrete structures,
Prof. Koji Sakai, Kagawa University, JAPAN

⑤ The mechanisms of brittle fracture of steel bars due to excessive ASR expansion of concrete,
Prof. Kazuyuki Torii, Kanazawa University, JAPAN

⑥ Cross-national comparison of concrete materials and messages for the future - Results of International Questionnaire Survey,
Dr. Kazuo Yamada, Taiheiyo Cement Co., JAPAN

Technical sessions were held in seven parallel sessions during three days of the conference on topics ranging from materials, structural performance, properties of fresh and hardened concrete, durability, recycling/reuse and applications (refer to **Table 5** shown below).

Along with the technical sessions, some interesting activities were added to the program for promoting information exchange among the participants. The extensive technical exhibition featured 14 organizations and companies which demonstrated advanced concrete technologies and recent developments. The exhibition was a useful opportunity for the participants to make new contacts during the coffee breaks. The distinctive program, especially for students, was a student tour visiting a famous historical and cultural place, Shirakawa-Go, Gifu. During the tour, students also enjoyed technical discussions with Prof. Keitetsu Rokugo (Vice-Chair of the local Organizing Committee, Gifu University) and Prof. Banthia. Another tour was also organized for the participants, a technical tour to visit typical infrastructures and industrial facilities in Nagoya and the vicinity. In addition to technical activities, a special event was organized for spouses and accompanying persons, a tour for experiencing traditional Japanese arts and crafts. It was a pleasure for the organizers to share fun time with all the participants.

Table 5: Session and number of papers

Session Title	Papers
Assessment, Health Monitoring	20
Environmental Design and Impacts	8
Fiber-Reinforced Concrete	23
High-Performance Concrete	17
Long-Term Performance	24
Performance under Severe Environment and Loading	13
Physical Properties and Constitutive Response	42
Strengthening and Repair	17
Recycling and Re-use	6
Test Methods for Performance Criteria	6
Lightweight Concrete	5
Behavior under Seismic, Fatigue and Impact Loading	6
New Design Concepts	4
Special Reinforcement	7
Other	11
Total	209

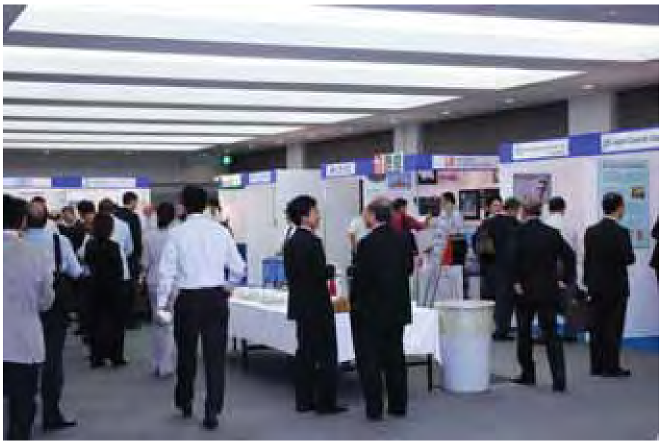

Photo 3: Technical Exhibition

Photo 4: Technical Tour

Photo 5: Student Tour

Photo 6: Accompanying Persons' Tour

The banquet on Tuesday evening at the Hotel Grand Court Nagoya featured a multi-course dinner, and traditional Japanese musical and other performances, Shishimai and Mochitsuki. This memorable evening was enjoyable for all, and Prof. Banthia introduced a plan for the next ConMat to be held in Canada.

During the closing session on Wednesday, Prof. Rokugo thanked the conference sponsors, JCI and the Kajima foundation, and summarized the conference activities. Prof. Rokugo also expressed appreciation for the efforts of JSCE, JCI and CSCE, and those of the Organizing Committee.

Photo 7: Conference Banquet

Photo 8: Banquet; Prof. Sakata (left) and Prof. Nagataki (right)

4. Report of questionnaire survey results (WG2)

Among 55 countries to which WG2 sent questionnaire forms, 29 people in 16 countries responded to the questionnaire. Highly interesting data were gathered, although the amount of information varied among questionnaire items depending on the field of specialization of respondents. The comments on each questionnaire item that reflect the current situation of each country are very valuable and helpful for mutual understanding of international differences. The summary and results of the answers to the questionnaire survey are described in the following sections.

4.1 Cement

(1) Changes in cement production volume

This section focuses on the global trend and characteristics of changes in cement production volume and its composition. The statistical data before 2008 were reviewed to study the trend, because the global economic crisis occurred in 2008, meaning that the data of the subsequent year were deemed unsuitable for trend study.

Figure 2 shows the breakdown of cement production in 1997 and 2006. These pie charts were based on the data of PCA[2]. In 1997, the top four countries (China, India, the United States and Japan) accounted for about 50 percent of global production, and the top 20 countries accounted for about 70 percent. However, a significant change has occurred in this trend for the next 10 years. In 2006, China accounted for nearly half of total global production, and the top 20 countries accounted for about 80 percent.

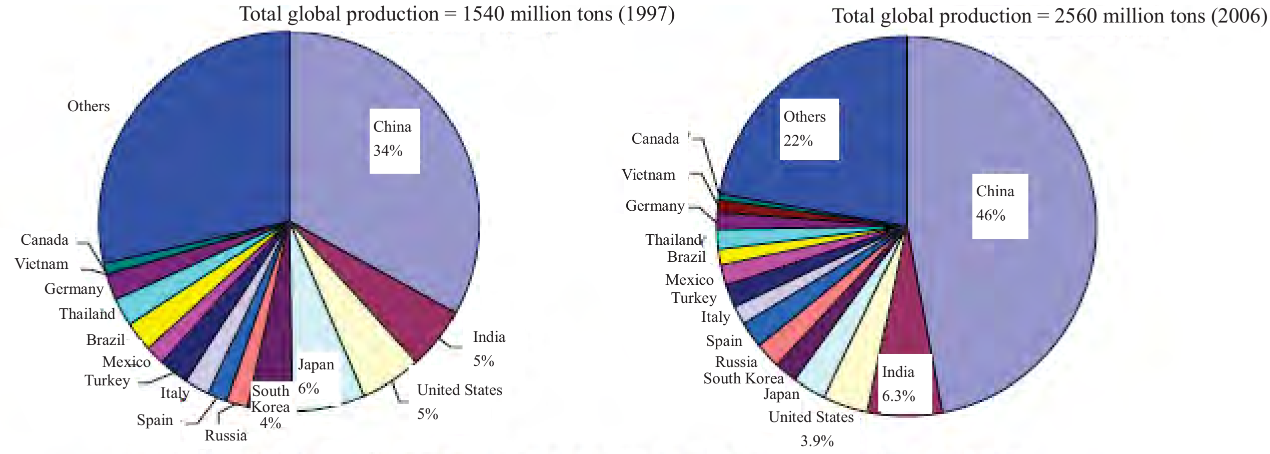

Figure 2: Breakdown of cement production in 1997 and 2006 (mainly based on data of PCA report[2])

In addition, cement production increased in most countries for 10 years from 1997 to 2006. **Table 6** shows the annual cement production in this period. The figures in the right-hand column of the table are the ratio of production volume in 1997 and 2001 to that in 2006. A characteristic trend is shown in Vietnam and Japan. For five years from 2001 to 2006, Vietnam achieved the highest growth rate in production, while Japan had the lowest rate. The production ratio of 2006 to 2001 of Japan fell below 1, meaning that only Japan showed a declining trend in production.

An interesting analysis of the trend in cement consumption was presented by Dr. Ouchi. **Figure 3** shows the cement consumption per capita in 2000 (including some data of 2007). According to the figure, the global average of cement consumption increased to 412 kg per capita in 2007, from 270 kg per capita in 2000. One characteristic is that oil-producing countries, wealthier countries and other countries enjoying remarkable economic growth appear at the top of the list. On the other hand, developing countries are seen at the bottom of the list, and major developed countries are ranked in the middle. However, it can be said that growth in demand for cement and concrete is expected in these countries.

Table 6: Statistical data on cement production volume (based mainly on data in the reference [2])

(Unit: million tons per year)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2006/1997	2006/2001
China	511	536	573	597	661	725	862	970	1038	1204	2.36	1.82
India	80	85	90	95	104	114	123	130	145	160	2.00	1.54
United States	80.6	81.5	83	85	89	88	92	96	95.7	99.7	1.24	1.12
Japan	92	81	80	81	77	72	69	67	69.6	69.9	0.76	0.91
South Korea	60	46	48	51	52	56	59	54	51	55	0.92	1.06
Russia	27	26	28	32	35	38	41	46	49	55	2.04	1.57
Spain	28	28	36	38	41	42	45	47	50	54	1.93	1.32
Italy	34	36	37	39	40	41	43	46	46	48	1.41	1.20
Turkey	36	38	34	36	30	33	35	39	43	47	1.31	1.57
Mexico	28	28	29	32	32	33	34	35	36	40	1.43	1.25
Brazil	38	40	40	39	39	38	34	34	37	40	1.05	1.03
Thailand	37	22	25	25	28	32	33	36	38	39	1.05	1.39
Germany	36	37	36	34	32	31	33	32	30	34	0.94	1.06
Vietnam				14	16	20	23	27	29	32		2.00
Canada	12	12	13	13	13	13	13	14	14	14	1.17	1.08
Others	440.4	443.5	448	439	451	474	491	517	578.7	568.4	1.29	1.26
Global Total	1540	1540	1600	1650	1740	1850	2030	2190	2350	2560	1.66	1.47

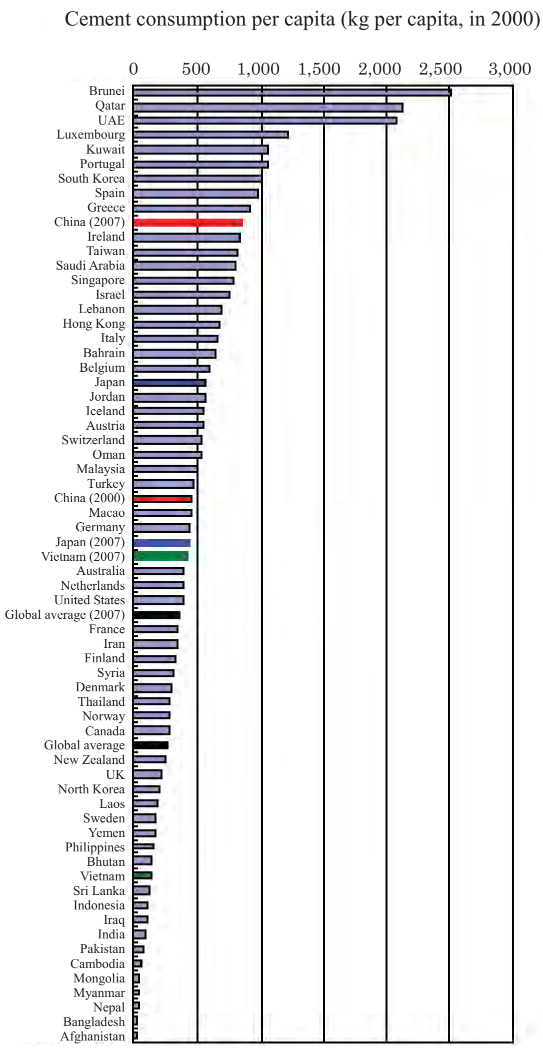

Figure 3: Cement consumption per capita (based mainly on the reference [3])

(2) Types of cement

Eighteen answers were received to the question about the types of cement. Portland cement is mainly used in Japan, South Korea, Taiwan, the United States, Canada, Singapore, Thailand, Philippines, Indonesia, Costa Rica, Switzerland and UK. On the other hand, blended cement is mainly used in China, Germany, Central European countries, Vietnam, Bangladesh and Kenya. According to the experience of the authors on this issue, blended cement is also widely used in France, Italy and Spain, although no answers were received in the questionnaire survey. As discussed later in the sections concerning mineral admixtures, even countries that mainly use Portland cement add mineral admixtures (called as Supplemental Cementitious Materials, SCM in the U.S. relating countries) to it in many cases. However, in Japan, it is not as common as in other countries, and plain concrete without mineral admixtures accounts for 80 percent of the total usage.

A characteristic change is shown in the types of cement used in Europe. **Figure 4** shows the changes in the types and strength class of cement used in Germany based on data provided by Verein Deutscher Zementwerke (VDZ)[4]. In the past 10 years, the percentage of Portland cement has tended to decrease while that of limestone cement has increased. This is attributed to the introduction of a carbon tax. With regard to the strength class, the percentage of Class 42.5 has increased. Traditionally in Europe, cement with a higher strength class has been used only for producing high-strength concrete and early strength concrete. On the other hand, cement with a lower strength class was used for concrete with normal strength. This is because the amount of powder material needs to be controlled within a certain range to produce concrete with higher workability, while general concrete having adequate amount of powder content can be produced with the lower strength-cement but not with higher strength-class cement, thus preventing the excessive use of high-strength cement except for only producing high-strength concrete.

In the United States and Australia/New Zealand, performance-based standards are established for cement quality, namely ASTM C 1157 and AS 3972/NZS 3122. According to Roumain[5], most states allow the use of cement in compliance with ASTM C 1157 under their building construction field. Some states also allow its use in construction work administered by the Department of Transportation (DOT). In Japan, the Japan Concrete Institute (JCI) established a research committee on concrete mineral admixtures, and has reviewed performance-based standards for cement quality that set performance requirements depending on the intended purpose, not regulating cement composition. More flexible cement composition permits more active use of by-products as cement materials, thus reducing CO_2 emissions significantly in the cement industry. It is also expected that the use of three-component cement will be facilitated.

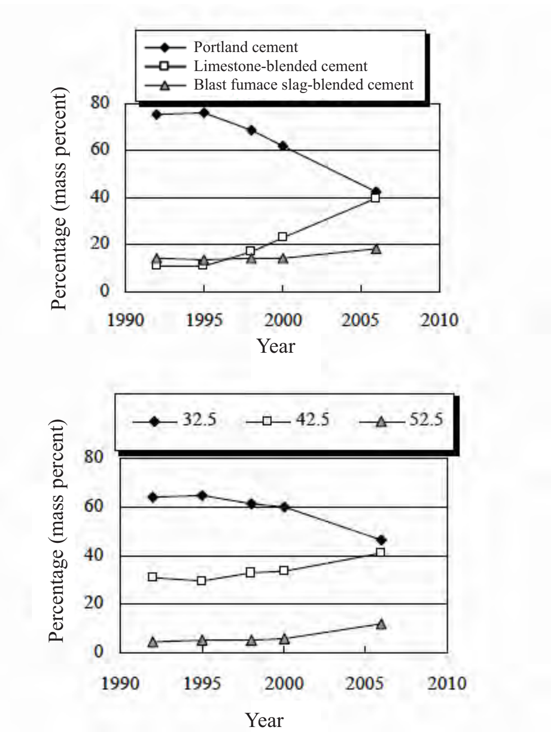

Figure 4: Changes in cement composition and strength class (in Germany) (based on the VDZ Annual Report[4])

(3) Waste utilization

The cement industry plays an important role in waste utilization around the world. The following descriptions are characteristic aspects:

- In many European countries, alternative fuel including meat-and-bone meal, garbage and biomass accounts for about 50 percent of the total fuel usage. On the other hand, it is not quite so common in the U.S. and Japan (the percentage of the use of alternative fuel is about 10 percent in the U.S.).
- One characteristic of Japan is the high usage rate of by-products as cement materials. In 2007, 486 kg of waste was used for producing a ton of cement.

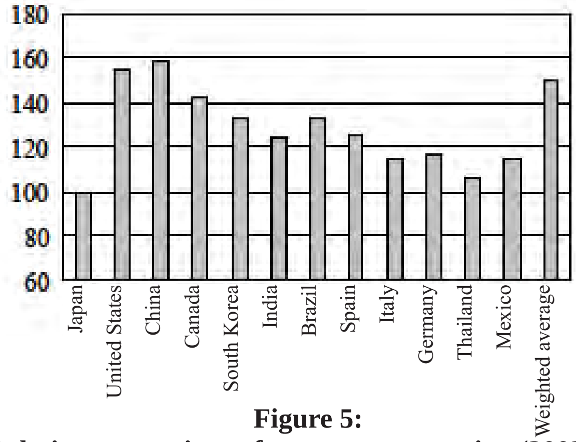

Figure 5:
Relative comparison of energy consumption (2003) [6]
Japan = 100 (3.44 GJ per ton of cement)

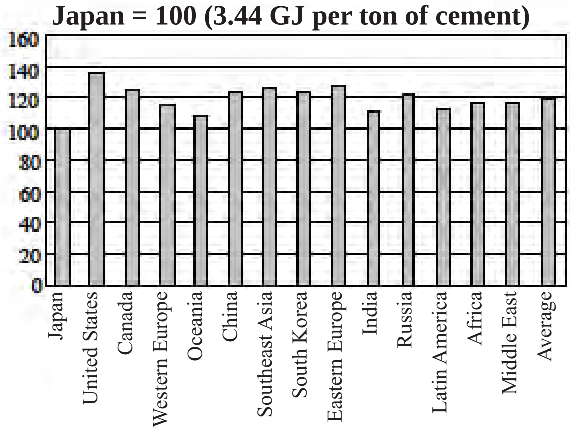

Figure 6:
Relative comparison of CO_2 emissions (2000) [6]
Japan = 100 (0.732 ton per ton of cement)

- Energy efficiency is one of the important factors in reducing the environmental load in cement production. **Figure 5** [6] is a relative comparison between countries as to the energy consumption for producing a ton of cement taking that of Japan as 100. The figure is based on data for 2003, and the energy consumption of Japan is 3.44 GJ per ton of cement. The figure shows that Japanese cement production technologies have achieved extremely high energy efficiency. **Figure 6** [6] is a relative comparison between countries regarding CO_2 emissions for producing a ton of cement taking that of Japan as 100 in the same way as in **Figure 5**. The figure is based on data for 2000, and the CO_2 emissions of Japan are 0.732 ton per ton of cement. The difference in CO_2 emissions between countries is smaller than that in energy consumption (**Figure 5**). In cement production, CO_2 is emitted mostly through decarboxylation of limestone, and there is not much difference in emission volume from different processes between countries. It seems that the difference of energy sources for burning materials causes the difference in CO_2 emissions.

(4) Standards

The standards of the United States and Canada are intended to increase the rate of substituting mineral admixtures for Portland cement with the purpose of reducing environmental load. According to Mr. Steve Kosmatka of the Portland Cement Association (PCA) in the U.S., ASTM C 150, a standard for Portland cement, permitted the substitution of limestone for up to 5 percent of cement in 2004. In addition, the revision in 2009 permitted the substitution of mineral additives as a process addition (additives that may be used when clinker is crushed) for up to 5 percent of cement, as well as that of organic substances for up to 1 percent of cement. In the light of these standards, when 5 percent of cement is replaced with limestone, another 5 percent with mineral additives as a process addition, 5 percent of gypsum, and 1 percent with organic substances, the clinker content in cement reaches 84 percent in theory.

Prof. Doug Hooton, the University of Toronto said that Portland-Limestone Cement (PLC) was added as a new class of cement in CSA A 3001, a Canadian cement standard. PLC is cement where up to 15 percent of the content is substituted with fine powder limestone. The use of PLC is prohibited under conditions where sulfate action may occur because of the increasing risk of thaumasite sulfate attack.

PLC also shows satisfactory performance when it is mixed with fly ash and slag. It was added in CSA A23.1 as usable cement in 2009, and will be covered under the National Building Code of Canada in 2010. A similar trend is shown in the United States. The development of cement similar to PLC has been promoted by defining the quality in compliance with ASTM C 1157. In the U.S., an important progress has achieved to unify ASTM and AASHTO standards on cement in 2009[7)].

Against such a backdrop, cement companies and universities are actively involved in research on sulfate attack in particular.

4.2 Regional characteristics in aggregate

Six answers were received (from Japan, Singapore, Thailand, Bangladesh, Canada and Netherlands) to the questions about aggregate. An extremely wide range of aggregate is used around the world depending on the geological and geographical conditions. The following descriptions are the characteristics of each country.

- Japan: Sea sand mining tends to be restricted. The shrinkage caused by sandstone aggregate has become known recently. Variety type of aggregate is now recognized to have possibility to be reactive. From the viewpoint of drying shrinkage and ASR, pure limestone is preferred to use in Japan.

- Thailand: Most coarse aggregate is made of crushed limestone, while fine aggregate is of river sand.
- Bangladesh: Coarse aggregate is made of sandstone, while fine aggregate is mainly of fine river sand. Coarser river sand is also mixed into fine aggregate when it is used for producing high quality concrete.
- Singapore: All aggregate is imported.
- Canada and northwestern area of North America: Natural glacier gravel is commonly used as aggregate.
- Netherlands: River gravel and sand is commonly used. It tends to be replaced with sea sand for the protection of the Rhine River and Maas River.

4.3 Mineral/chemical admixtures

With the help of the BASF group, data on mineral/chemical admixtures that are used in 15 countries were obtained. The data were classified by concrete production methods to summarize the answers to the questionnaire survey. The classification categories include ready-mixed concrete (RMC), precast concrete (PCa) and on-site mixed concrete. **Figure 7** shows the breakdown of concrete production methods in each country. In addition, the breakdown of chemical admixtures (AE water-reducing admixture (WR) or high-range AE water-reducing admixture (SP)) that are used in RMC and PCa was studied as shown in **Figure 8**. The usage rate of each type of chemical admixture including lignin sulfonate (Lig), naphthalenesulfonate (BNS), melaminesulfonate (MM) and polycarboxylate (PC) was also calculated. The same calculation was made with regard to chemical admixtures.

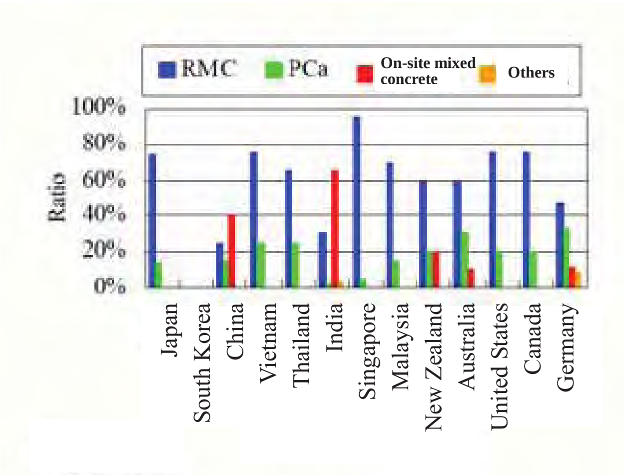

Figure 7: Concrete production methods

(1) Comparison of concrete production methods

A different trend was observed between developed and developing countries. In developed countries, RMC is mainly used with a little bit of precast concrete. In developing countries, on the other hand, on-site mixed concrete accounts for a major part of the total concrete usage. **Figure 7** was drawn from raw data, and needs to be interpreted with care regarding the data for Vietnam and Thailand. The percentage of on-site mixed concrete in both countries is 0 percent in the figure. However, this may be the percentage of RMC containing admixtures. Mr. Atsushi Matsui, Nghi Son Cement, said that concrete is mixed on site in many cases although it is difficult to present any data. RMC accounts for 60 percent of concrete usage in Thailand, while it does so for only 20 percent in Bangladesh.

Another characteristic of on-site mixed concrete is that it is measured by volume. No mineral/chemical admixtures are used, and the amount of water needed to ensure the workability of concrete is added.

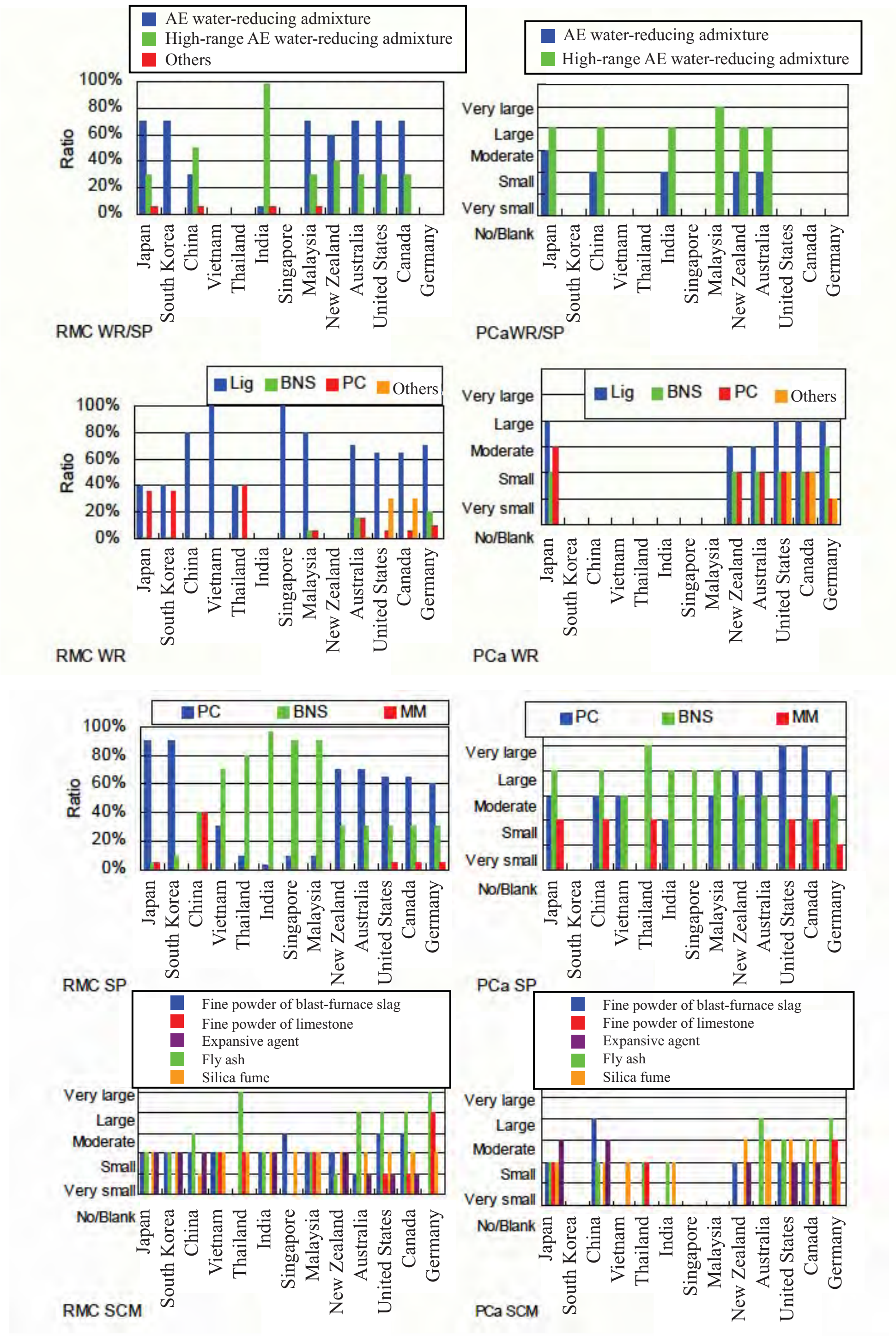

Figure 8: Usage situation of admixtures in each country

(2) Chemical admixtures

In **Figure 8**, China and India show an extremely high percentage of high-range AE water-reducing admixture (SP) for RMC. With regard to the principal components of SP used in RMC, naphthalenesulfonate (BNS) is mainly used in warmer regions including Vietnam, Thailand, India, Singapore and Malaysia. This is probably because BNS maintains high performance under high temperature, and is offered at relatively reasonable prices.

(3) Mineral admixtures

Mineral admixtures are less frequently used in Japan, South Korea, Vietnam and Bangladesh, while fly ash and slag are actively used in RMC plants in Thailand, the U.S., Canada, Germany, England and Australia. Expansive agent is often used in precast concrete to prevent drying shrinkage.

4.4 Concrete production

Unit water content: Only Japan, South Korea and Costa Rica have an upper limit of unit water content of concrete. It seems that no limits are set in Europe, Thailand and Bangladesh. As is the case with the following sections, the Southeast Asian and African countries have established standards based on those of their former suzerain states, thus sharing similar features.

Regulation of the content of chlorides: First of all, there are two types of methods for describing chlorides content, i.e., by using the mass ratio against cement (mass ratio method) or the total content per unit volume of concrete (total content method). As steel corrosion depends in theory on the concentration of free chloride ions in cement paste, the mass ratio method would be suitable to describe the chloride regulation. On the other hand, however, there was a comment saying that the total content method has been used in Japan taking the human factor in concrete production into consideration. Only a limited number of countries including the Oceania region and South Korea use the total content method. However, in South Korea, it is partially shifting to the mass ratio method.

Many countries including Thailand and Bangladesh have not yet introduced any regulations on the chloride ion content, even though the need is acknowledged. There was a comment that the mass ratio method is reasonable when any regulations are introduced, because ASTM and EN standards are commonly applied.

Alkali-silica reaction (ASR): Some countries including Japan are still using the chemical test and/or the mortar bar test to assess the reactivity of aggregate. As was pointed out recently, it needs to be kept in mind that aggregate with delayed-expansive properties or pessimum effects is not assessed properly by using these test methods. In Thailand, ASTM standards are commonly used, and the ASR is assessed according to ASTM C 1260. The issues concerning ASR include a significant gap between countries in awareness of risk (Japan is behind other advanced countries in terms of understating pessimum effects and delayed expansion caused by crypto/microcrystalline quartz), and there is difficulty in obtaining non-reactive rocks or pozzolans including fly ash even though a country like Switzerland has intention to take measures against ASR.

Sulfate attack: This issue definitely affects the Middle East, the U.S., Canada and Europe mainly, but it is regarded as a potential issue in many countries. Measures against deterioration caused by ettringite formation can be taken easily in many cases when blended cement, fly ash and other types of pozzolan can be used. However, the physical sulfate attack caused by evaporation of groundwater near ground surface that occurs in the Middle East is not adequately understood even by the American Concrete Institute (ACI), and appropriate measures have not yet been taken.

4.5 Durability design

Performance-based design is the latest trend that is drawing a lot of attention in the academic field. However, there are still some issues to be solved for practical application. In the Netherlands, a shift from specification-based design to performance-based design has been discussed. According to Dr. Joost Guiliker of the Ministry of Transport, Public Works and Water Management, it is possible to present a concrete mix with a service life of 100 years, but there are no means of verifying the validity. He said that the current issues were that no criteria, assessment methods and demonstration data have been established. With regard to salt damage, the biggest concern for reinforced concrete (RC) structures, for example, a chloride diffusion coefficient can be calculated from experimental data with relation to the materials and mixing conditions of concrete, and a future prediction can be made. However, it is difficult to verify the quality of cover concrete of actual structures with the current technologies.

4.6 Steel Reinforcement

Five answers were received from respondents in Japan, Netherlands, South Korea, Bangladesh and Costa Rica. Electric furnaces are used for producing steel reinforcement in all of these countries. Cold-working is used in the Netherlands only. In Bangladesh, hulks of old ships are purchased to recycle steel, but there are also work environment issues.

5. Future of concrete materials

5.1 Cement industry

The G8 summit set a goal of halving global CO_2 emissions by 2050. According to Herfort[8), with regard to CO_2 emissions in the cement industry, there is an estimation that 2 gigatons of CO_2 were emitted for producing 2.5 gigatons of cement in 2006 in the world. It is predicted that cement production will continue to rise in the future. If the same production systems as today are still used then, emissions will double increasing to 4 gigatons in 2050. To achieve the emission goal by 2050, CO_2 emissions need to be reduced by 3 gigatons through technological innovation.

Improvement in production efficiency and utilization of alternative fuel: First of all, the practical application of the latest cement production system is needed. Then, the use of alternative fuel including waste oil and biomass needs to be considered as a means of reducing CO_2 emissions. It is estimated that CO_2 emissions will be reduced by 0.93 gigatons when these measures are taken.

Use of mineral admixtures: A secondary measure is to promote the use of general mineral admixtures including a fine powder of blast-furnace slag and fly ash. However, there is a limit to the use of these mineral admixtures in terms of production volume and distribution. Therefore, the promotion of the use of fine powder limestone is considered as an alternative measure. Using fine powder limestone with activated alumina makes it possible to maintain the strength[9)]. It is estimated that CO_2 emissions will be reduced by 0.88 gigatons when these measures are taken.

CO_2 absorption through concrete carbonation: Carbonation is one of the deterioration phenomena of concrete, but it contributes to a reduction in CO_2 emissions from a different perspective. In fact, it is estimated that CO_2 emissions can be reduced by about 0.34 gigatons through carbonation.

CO_2 emissions can be reduced by 2.13 gigatons in total when all the measures mentioned above are carried out. However, a further reduction by 0.83 gigatons is needed to achieve a target of 3 gigatons. As additional measures, if geopolymer or any other materials with a lower CaO content can be used as binder, or if the composition of the interstitial phase in cement can be changed by decreasing the burning temperature[10)], a significant reduction will be achieved. Besides, still other technology such as carbon storage may be required to satisfy the target.

5.2 New technologies

(1) New materials — A case of the United States

High Volume Fly Ash (HVFA) concrete: HVFA is concrete where more than 50 percent of the cement contained is substituted with fly ash. This is drawing attention due to its high performance in reducing CO_2 emissions, as well as controlling hydration heat, alkali-silica reaction and sulfate attack. The details is described in "High Performance, high Volume Fly Ash Cocrete" published by Malhotra and Mehta.

Crushed stone powder: The use of crushed stone powder (with a particle size of 75 μm below), a by-product of aggregate, is being promoted. Even if 20 percent of fine aggregate is substituted with crushed stone powder, adequate workability, high permeation resistance and high bending strength are obtained by using appropriate mineral admixtures.

Permeable concrete: This is called porous concrete in Japan. Permeable concrete is being used for permeable pavement of roads and parking lots in the U.S. recently.

(2) New construction methods

Ultra-high strength concrete: The use of ultra-high strength concrete with a strength of more than 200 through 250 MPa has increased in the construction of superhigh-rise buildings. In South Korea, for example, such concrete is used for the foundation of superhigh-rise buildings. In addition, ultra-high strength fiber reinforced concrete (UFC) has also come into practical use in large-scale construction projects. A recent example in Japan is for the runways of Haneda Airport in the expansion project.

Self-compacting concrete (SCC): SCC has already been used commonly in Europe, and its use has expanded in many countries. A portable rheometer was developed in the U.S. recently to address rheology control, one of the key factors for using SCC.

(3) Current material problems each country faces

Drying shrinkage: Many countries point out drying shrinkage as a material problem. Japan, Thailand and Costa Rica commented on the topic in the questionnaire survey. In particular, many cases of drying shrinkage and a high degree of strain found in sandstone aggregate were reported. A lot of problems of deterioration caused by drying shrinkage have also been reported in Japan. The unexpected deformation for a girder of prestressed concrete bridge that seems to be caused by drying shrinkage was also found in Costa Rica.

ASR: Many cases of fracture of steel reinforcement have been reported in Japan, and the control of alkali-silica reaction is urgently needed.

There is an increasing interest in ASR problems similarly in South Korea and Thailand. However, there is a problem that there is a lack of human resources specialized in the petrological assessment of aggregate.

Delayed Ettringite Formation (DEF): Prof. David Fowler, of the University of Texas at Austin, said that the expansion and deterioration resulted from Delayed Ettringite Formation (DEF) was a serious problem in the U.S. DEF is caused by high-temperature steam curing, and lowering the upper limit of the curing temperature is considered as a solution.

(4) Improvement in construction system

The environmental load is a key assessment point in the selection of concrete materials and construction methods. It is necessary to establish quantitative assessment methods for the environmental impact of materials and construction methods.

While such an advanced field is drawing attention, some fundamental problems concerning the production of durable concrete are still left unsolved. In Japan, further efforts are required in ensuring the adequacy of cover concrete and the uniformity of aggregate grain size. It is believed that developing countries face more challenges. Comprehensive training and improvement in the construction system are needed.

(5) Maintenance and management policy

Quality assessment and residual life prediction: These are difficult even for components like columns and beams. There are many problems to be solved for the assessment of entire structures such as buildings and bridges. The Japan Society of Civil Engineers set up Committee 331 (Chairman: Professor Takumi Shimomura, Nagaoka University of Technology) recently, and has discussed quantitative assessment of steel corrosion, quality estimation by probabilistic measures, numerical analysis of deteriorated structures, as well as establishment of quality assessment methods using nondestructive tests.

Monitoring: Radio Frequency Identification (RFID) technologies are used to monitor strain and other properties of actual structures[11)] in Japan. Data are stored in a RFID tag buried in concrete by connecting it with a strain gauge placed on reinforced concrete. The data can be read from the outside of the concrete by using radar. This technology is expected to be widely applied such as to compaction sensors and corrosion sensors.

According to Prof. David Fowler, research on the health monitoring is conducted actively in the United States, and the development of remote sensing systems for defects including steel corrosion, deformation and cracks has been promoted. PCA has also conducted on-line monitoring of bridges on a trial basis in recent years.

Repair: The development of repair materials remains a critical issue. Further development is required in the durability prediction of repair materials as well as the residual life assessment of repaired structures. Unfortunately, it was difficult to obtain any specific information on this topic in the questionnaire survey.

6. Field survey

In parallel with the questionnaire survey, a field survey was conducted to understand the actual situation in each region. Among Southeast Asian countries that are relatively close to Japan, two countries were selected for the survey including Thailand (Bangkok) as a developed country, and Bangladesh (Dhaka) as a developing country having expectation for future growth.

In Bangkok, the cooperation of Mr. Boonrawd Kuptitanhi, the Concrete Products and Aggregate Co. Ltd. of the Siam Cement Public Company Ltd., was gained through Prof. Somnuk Tangtermsirikul, Thammasat University. In Dhaka, the cooperation of Prof. M. A. Noor, a specialist of concrete and ABC Building Products Ltd. was obtained through Prof. M. A. Ansary, Bangladesh University of Engineering and Technology (BUET).

In both countries, ready-mixed concrete plants are at least partially equipped with two-axis forced concrete mixers with automatic measuring functions. Ready-mixed concrete is transported within 90 minutes, and constructed by using concrete pumps and internal vibrators. There is not much difference from Japan in these processes. Ready-mixed concrete trucks equipped with a Global Positioning System (GPS) are effectively used in Bangkok.

Hot weather concrete is always used under a continuous high temperature of around 40°C. The strength test specimens were cured in an outdoor water tank up to a specified material age without being subject to temperature control. The quality of high-strength concrete is considerably lower than that of Japan. A common aspect between Thailand and Bangladesh is that they are eager to implement large-scale construction projects as soon as they can acquire the budget.

On the other hand, the difference between both countries and from developed countries is the percentage of advanced plants. Apart from international construction projects that overseas companies participate in, on-site mixing is mostly used in general. The use of ready-mixed concrete accounts approximately for 40 percent in Bangkok, and 20 percent in Dhaka. In particular, in Dhaka, concrete is usually measured by volume by using a bucket on site, and water is added so that a specified slump is achieved. In most plants in Thailand, three types of cement including Ordinary Portland Cement, fly ash cement and blast-furnace cement can be provided for producing ready-mixed concrete. In Bangladesh, a type of CEM II42.5 cement in accordance with EN standards, namely fly ash cement, is mainly used.

The issues that Thailand faces are the unstable government that obstructs implementation of the budget for construction work, and the control of cover concrete as in Japan.

In Bangladesh, 52 cement companies (all of them are cement grinding plants except for two clinker plants) are competing with each other, and 22 million tons of cement are used by 140 million people. The cement and concrete industries will soon enter the phase of a business generating big profits. The problem is, however, that the number of substandard products has increased sharply under time and budget constraints on improvement in the average level of technologies. Fine sand (with a Fineness Modulus of 1.1) from a large delta of the Ganges River including sandstone, as well as crushed bricks, are commonly used as coarse aggregate. One characteristic is that bamboo support for concrete casting is used for the construction of ordinary buildings, except for high-rise ones, reflecting economic circumstances. A similar trend is seen in Vietnam.

7. Summary

A wide range of concrete materials are used around the world reflecting regional characteristics. With the purpose of promoting mutual understanding and sharing information on international differences, questionnaire forms were sent to each country to ask about materials used. Valuable answers and comments on the situation in each region were received from 29 respondents in 16 countries. The following descriptions are the findings from the questionnaire survey:

1) Cement: Cement production volume has continued to rise around the world, and the composition has been changed to blended cement in recent years. The cement industry has a major role to play in waste utilization.
2) Aggregate: Drying shrinkage and ASR issues in Japan were discussed in this report. There are still some issues to be solved in the field of concrete production. A wide range of aggregate is used depending on the geological conditions in each country.
3) Mineral/chemical admixtures: The mineral/chemical admixtures that are used in each country were worked out from numerous data. In particular, the usage of pozzolan was completely different from region to region.
4) Future vision: Measures to reduce CO_2 emissions were proposed in this report. To achieve the emission target by 2050, a variety of approaches from every aspect need to be taken. Furthermore, new materials, construction methods and monitoring systems in each country were introduced, and the issues that each region faces, including drying shrinkage, ASR and DEF, were discussed.

Acknowledgement

We would like to extend our appreciation to all participants for ConMat'09 and parties concerned for many valuable comments and answers in the questionnaire survey. ConMat'09 was full success conference in view of research information exchange and the promotion of further researches. As for the survey, not all comments were published in this report because of space limitations, but they were greatly helpful for us to understand the current situation in each country.

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