Committee Report : JCI- TC113A

Technical Committee on Evaluation of Influence for Performance and Execution of Concrete with Mineral Admixtures

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Abstract

From the viewpoint of effective use of resources for environmental considerations, there are increasing social demands for use of construction by-products to reduce environmental loads. In line with this, it is expected that the use of blended cement containing materials such as granulated blast-furnace slag and fly ash as well as the proactive use of such by-products as “admixtures” will be expanded. The required quality and usage of such materials are defined by JIS and construction guidelines published by relevant academic institutes. In this way, the conditions for use have been established, but the use of such materials is far from widespread. Against such a background, the Committee has carried out activities with the purpose of sorting out issues for proactive use of by-products as concrete material, presenting solutions to individual issues, and proposing actions toward expansion of applications.

Keywords: Admixtures, granulated blast-furnace slag, fly ash, performance evaluation, construction and durability

1. Purpose of the Committee

From the viewpoint of effective use of resources for environmental considerations, there are increasing social demands for use of construction by-products to reduce environmental loads.

By-products such as granulated blast-furnace slag and fly ash have effects for improvement of concrete quality when used as replacement for part of cement, and have been used as “additives” for blended cement since long ago. On the other hand, there are expectations for proactive use of these by-products as “admixtures” with different quality and a rate of replacement of cement depending on the intended use so as to achieve such effects in a more reasonable manner.

The required quality of granulated blast-furnace slag and fly ash as concrete material is defined by JIS on an individual basis[1), 2)]. Furthermore, construction guidelines on concrete containing these materials are provided by the Japan Society of Civil Engineers (JSCE) and the Architectural Institute of Japan (AIJ) [3)-7)]. In this way, the conditions for use of these by-products as admixtures have been established, but under present circumstances, there use is far from widespread.

Against such a background, the Committee has carried out activities with the purpose of sorting out issues for proactive use of by-products as concrete admixtures, presenting solutions for individual issues, and proposing actions toward expansion of applications.

2. Overview of activities by the Committee

2.1 Policies and structure of working groups (WG)

The Committee consists of two working groups (WG), the Material WG and Construction WG, as shown in **Table 1**, and has carried out activities according to the policies below:

- Admixtures to be studied are granulated blast-furnace slag and fly ash.
- It is assumed that by-products are used as admixtures, but use as additives is also studied in consideration of actual situations.
- The Committee evaluates quality of admixtures and the effects on concrete quality from scientific viewpoints.
- The Committee studies key points to note and measures in manufacturing and construction of concrete containing admixtures.
- The Committee explores a direction for proactive use of by-products by looking ahead to the way it should be handled based on actual situations.

2.2 Overview of activities by Material WG

Material WG held seven meetings in two years mainly to identify the issues in expansion of use of granulated blast-furnace slag and fly ash, and study measures to solve them as described below:

(1) Evaluation of the effects of admixtures on concrete performance

Concrete containing admixtures exhibits strength development, crack resistance, neutralization rate and durability different from that of general concrete. In particular, ambient temperature significantly influences the effects of admixtures on concrete performance. Therefore, it is essential in use of admixtures to have correct understanding of these factors through evaluation based on scientific knowledge.

Table 1: Committee Members

Chairman of Committee	Shigeyuki SOGO	Hiroshima Institute of Technology
Secretary of Committee	Hirotaka KAWANO	Kyoto University
Secretary of Committee	Takafumi NOGUCHI	The University of Tokyo
Chief of Subcommittee	Ryuichi CHIKAMATSU	Obayashi Corporation
Chief of Subcommittee	Shingo MIYAZAWA	Ashikaga Institute of Technology
Vice chief of Subcommittee	Hiroyasu NARUSE	Mitsubishi Materials Corporation
Vice chief of Subcommittee	Kenro MITSUI	Takenaka Corporation
Committee members	Daiki ATARASHI	Tokyo Institute of Technology
	Yoshitaka ISHIKAWA	Electric Power Development Co.,Ltd.
	Tetsuya ISHIDA	The University of Tokyo
	Takeshi IYODA	Shibaura Institute of Technology
	Shinji URANO	Shimizu Corporation
	Takayuki OSATO	East Japan Railway Company
	Tadatsugu KAGE	Building Research Institute
	Hideyuki KAJITA	Maeda Corporation
	Yasushi KAWASHIMA	Sumitomo Osaka Cement Co.,Ltd.
	Shusuke KUROIWA	Taisei Corporation
	Sachie SATO	Tokyo City University
	Shigayuki DATE	Taiheiyo Materials Corporation
	Hideaki TANIGUCHI	Sumitomo Mitsui Construction Co., Ltd.
	Yasuhiro DAN	Nippon Steel & Sumikin Blast Furnace Slag Cement Co.,Ltd.
	Toyoharu NAWA	Hokkaido University
	Nobukazu NITO	DC Co.,Ltd.
	Shoji NOJIMA	Nippon Expressway Research Institute Co.,Ltd.
	Makoto HIGAKI	FLOWRIC Co.,Ltd.
	Jun-ichi MIYAKE	JP Hytec Co.,Ltd.
	Chiaki YOSHIZAWA	JFE Mineral Co.,Ltd.
	Hiroshi WATANABE	Public Works Research Institute

(2) Quality evaluation test of concrete containing admixtures

In many cases, the quality of concrete containing admixtures is evaluated by the same test method as that for general concrete. However, evaluation results may vary depending on test conditions, and sometimes differ from performance in actual structures. Therefore, it is necessary to identify issues in testing methods for concrete containing admixtures, in particular, those for strength development, crack resistance and neutralization rate, in consideration of curing methods.

(3) The status of use of admixtures

To expand the use of admixtures in concrete, it is important to know the current status of use. In particular, it is necessary to know the patterns of usage of granulated blast-furnace slag and fly ash (as blended cement or as admixtures), major structural components and structures that they are applied to, regional differences and a supply system, and then, identify issues and study measures for expanding their use.

(4) Requirements of laws, regulations and standards

One of the important issues for expanding the use of admixtures is to sort out laws, regulations and standards to be observed in the use of concrete containing admixtures. In particular, many of those concerning reduction of environmental loads cover the use of admixtures. It is necessary to sort out issues from a broader perspective such as reduction of CO_2 emissions, effective use of resources, and waste disposal.

2.3 Overview of activities by Construction WG

Construction WG held eight meetings in two years, and discussed issues and measures for proactive use of admixtures in concrete and manufacturing, and production of such concrete. An overview of activities by issue is described below:

(1) Measures to ensure quality of concrete

If the use of admixtures incurs any disadvantages, they tend to be avoided even if they also have advantages. It is particularly important to deduce how to compensate for negative effects in strength development and crack resistance due to the use of admixtures, if any. Furthermore, it is unavoidable that there will be variability in the quality of materials containing construction by-products, and they should be used on the understanding of such variability.

(2) Supply system and manufacturing facilities

Manufacturing bases for granulated blast-furnace slag and fly ash are unevenly distributed in Japan. They are materials manufactured where they are consumed, unlike cement for which distribution systems are established nationwide. In addition, if they are used as admixtures in a ready-mixed concrete plant, the plant needs to have material storage facilities. In general, ready-mixed concrete plants have several storage bins to allow for use of different types of cements. However, they are often occupied, and some coordination may be needed if additional admixtures are used.

(3) Patterns of usage

Granulated blast-furnace slag is mainly used as additives for Class B portland blast-furnace slag cement and less frequently used as admixtures. Fly ash has been used in replacement with cement in concrete in many dam construction works and recently, there are many cases where fly ash is premixed with cement and supplied in the form of blended cement.

On the other hand, fly ash is sometimes used as replacement with aggregate. Furthermore, a study has been promoted to blend fly ash as supplement for microparticles in fine aggregate. It is necessary to study the handling of admixtures when they are blended in concrete with the aim of utilizing their properties as powder, not as a bonding agent.

(4) Handling in manufacturing and construction

In civil engineering, admixtures are sometimes used at a higher replacement rate than that defined for blended cement. This results in considerable difference in quality as compared to ordinary concrete, and brings issues in handling to keep in mind during manufacturing and construction. Curing is particularly important among construction measures to ensure durability and crack resistance.

In construction work, granulated blast-furnace slag and fly ash are less frequently used as admixtures. Their negative effects on strength development and neutralization hinder proactive use. Curing at construction sites is one of the issues to be addressed.

3. Overview of achievements by the Committee

The Committee drew up a report of the results of activities. It also plans to hold a seminar and publish the result in 2013.

The committee report consists of three parts. Part 1 describes proposals for expansion of use of admixtures summarized by secretaries of the Committee based on the discussions by two working groups. Part 2 was prepared mainly by Material WG, and describes a scheme to be established for proactive use of admixtures. Part 3 was prepared mainly by Construction WG and describes construction that supports proactive use of admixtures.

3.1 Table of contents of the report

The table of contents of the report is listed below:

[Main text]

Part 1 Proposals for expansion of use of admixtures

1.1 Purpose of use of admixtures

1.2 Limitations on practical use

1.3 Proposals for proactive use of admixtures

Part 2 A scheme to be established for proactive use of admixtures

2.1 Design issues and proposals

2.2 Issues and proposals regarding material specifications

2.3 Issues and proposals regarding concrete specifications

Part 3 Construction that supports proactive use of admixtures

3.1 Issues and proposals regarding supply of admixtures

3.2 Issues and proposals regarding production of concrete containing admixtures

3.3 Issues and proposals regarding execution of concrete containing admixtures

[References]

Reference 1 The status of use of admixtures

Reference 2 The findings of recent research on proactive use of admixtures in concrete

Reference 3 Examples of use of admixtures

Reference 4 Examples of applications of admixtures in structures

Reference 5 The overseas status of use of admixtures

3.2 Proposals for expansion of use of admixtures

3.2.1 The ways in which systems and design should be implemented

(1) Issues related to systems

Laws, regulations and standards play a major role in the proactive use of admixtures in concrete. For example, the "Law on promotion of transition toward low-carbon cities (the Low Carbon City Promotion Act)" recognizes the effects of admixtures for reducing CO_2 emissions, and gives consideration to expansion of their use. In the field of civil engineering, the enactment of the Law on Promoting Green Purchasing has accelerated the widespread use of portland blast-furnace slag cement in public works. There are also other systems such as the Eco-Mark certification program, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), and certification programs of environmentally-friendly products run by local governments.

These systems are recognized as effective for utilization of resources and reduction of CO_2 emissions in terms of use of portland blast-furnace slag cement and portland fly-ash cement. However, they do not fully contribute to widespread use of admixtures yet and further studies are needed in the future. On the other hand, if the use of such by-products is standardized, they will need to be transported to consumption areas nationwide, resulting in increased consumption of transportation energy. It would be effective to develop local standards as necessary, not a uniform standard throughout the country.

The report also introduced the trends in the International Organization for Standardization (ISO) as overseas specifications for admixtures. ISO/TC 71 (a technical committee on “concrete, reinforced concrete and pre-stressed concrete”) has carried out tasks for standardization of fly ash and silica fume. In addition, ISO 21965 (Concrete), an ISO standard concerning ordering and manufacturing of concrete published in 2007, uses the k-value to measure the degree of contribution of admixtures to concrete reactivity, strength development, resistance to chloride penetration and resistance to neutralization. The report summarized the k-values recommended by ISO, and the conditions for application to fly ash and granulated blast-furnace slag.

(2) Design issues and proposals on civil engineering structures

The Standard Specification for Concrete Structures published by the Japan Society of Civil Engineers (JSCE) reviewed the design value for the diffusion coefficient of chloride ion in the revision in 2013 to appropriately evaluate the durability of concrete containing additives. The report introduced the findings of research on the permeability of chloride ion into concrete containing admixtures, and summarized the relation to the revisions of the Standard Specification for Concrete Structures.

In the Standard Specification for Concrete Structures, the design value of neutralization rate coefficient for concrete containing admixtures is set larger than that for concrete made from ordinary Portland cement (OPC) only. On the other hand, many of the research results in actual structures are not much different between the two. However, this was not incorporated into the revision in 2013 because of lack of accumulated data. Future actions to be taken are to accumulate data on neutralization in actual structures, and to study an accelerated neutralization test method that allows for appropriate evaluation of neutralization resistance of concrete containing admixtures.

In the Specifications for Highway Bridges, ordinary Portland cement, early-strength Portland cement and portland blast-furnace slag cement are assumed to be the materials used, while fly ash and granulated blast-furnace slag are the admixtures to be used. The Specifications stipulate that portland blast-furnace slag cement is used for substructures in general, but provides supplementary information that strength and durability may be compromised depending on curing conditions when portland blast-furnace slag cement is used. In addition, shrinkage and creep characteristics of portland blast-furnace slag cement concrete are not necessarily defined clearly, and therefore, tests need to be done when such concrete is used. However, the Specifications for Highway Bridges define no design values for shrinkage and creep of such concrete. If test results are different from those of OPC or early-strength Portland cement, it is difficult to determine if such concrete can be used. It is important to accumulate experience in the use of concrete containing admixtures, and to this end, further improvements in systems that encourage proactive use of admixtures are expected.

(3) Design issues and proposals on use in buildings

The Building Standards Law stipulates the quality of construction materials used in buildings. Specifically, concrete that meets the JIS or is approved by the minister of a competent authority may be used in building foundations and major structural components.

The “Housing Quality Assurance Law” stipulates that corrosion of reinforcements due to neutralization and deterioration due to freezing and thawing are evaluated, and defines the upper limit of a water-cement ratio depending on the degree of deterioration and structural components to be used. The law also stipulates that the mass of fly ash and 30 percent of the mass of blast-furnace slag are excluded from that of cement in calculating a water-cement ratio. In some cases, however, it is approved that the mass of blast-furnace slag is included depending on the parts where concrete is constructed and covering depth.

3.2.2 Proactive use as cement additives

(1) Promoting the use of cement in response to the transition towards a low-carbon society

The cement industry has greatly contributed to both the society and the environment through technologies for treatment of industrial waste and by-products, although the domestic demand for cement has been sluggish. As shown in **Figure 1**, more than 450 kg of industrial and general waste are used to produce a ton of Portland cement. To further increase the ratio, new treatment technologies are required in terms of quality. On the other hand, however, there is increasing social demand for further reduction of CO_2 emissions by construction materials, in particular cement, that are consumed in a substantial volume.

To address this, the government has implemented environmental measures that encourage the use of additives. With the recent enactment of the “Law on promotion of transition toward low-carbon cities (the Low Carbon City Promotion Law),” the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Economy, Trade and Industry and the Ministry of Environment held a "Conference for development of certification criteria for low-carbon buildings" and drew up a preliminary draft of the criteria. The criteria include an option that "portland blast-furnace slag cement or fly ash cement is used in critical parts to ensure the load-bearing capacity of structures."

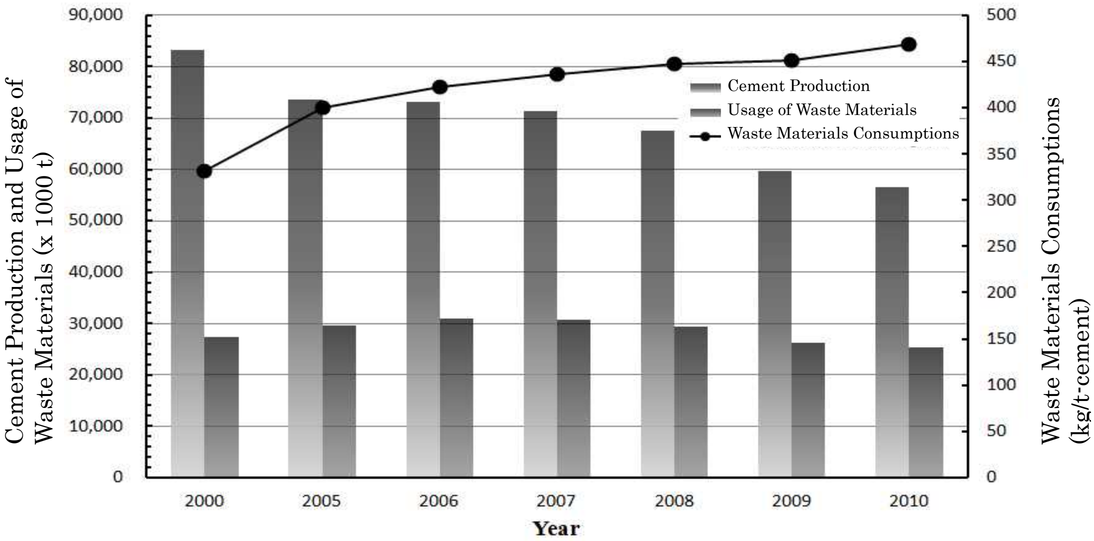

Fig. 1: Changes in cement production volume and usage of waste

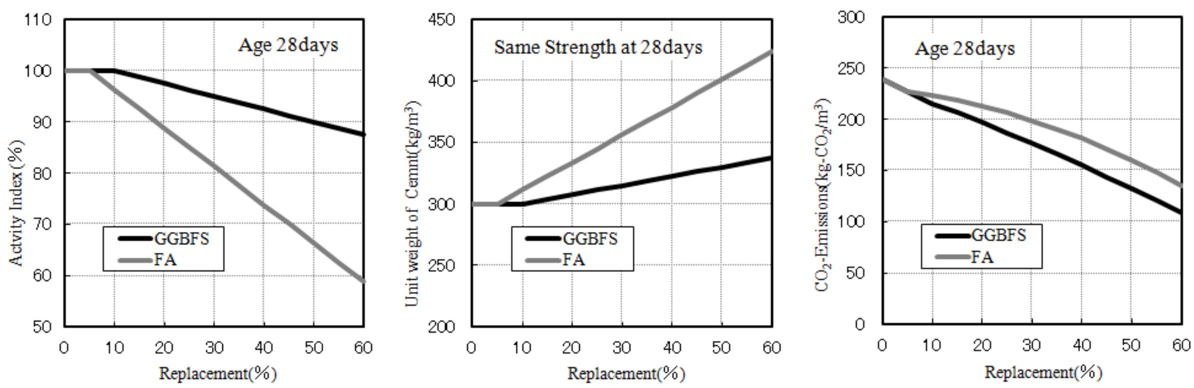

Fig. 2: Examples of trial calculation of the relations between mortar intensity ratio, unit weight of cement and CO_2 emissions in relation to a replacement rate with blast-furnace slag or fly ash

Figure 2 shows examples of a trial calculation of CO_2 emissions when part of OPC is replaced with blast-furnace slag or fly ash under the condition that the strength of cement is maintained. There is no doubt that the amount of CO_2 emissions becomes larger as more cement is produced. In the manufacture of Portland cement that has achieved the highest level of CO_2 reduction in terms of energy efficiency, expanding the scope of additives to be used and encouraging the use of blended cement would be effective for further CO_2 reduction.

Unlike ISO standards, the cement specifications in Japan have neither upper limits nor categories of strength, and therefore, users tend to place emphasis only on strength during construction without paying attention to concrete durability. This could contribute to early deterioration of concrete that has been seen recently such as temperature stress crack due to increase in heat with increased strength of cement, and drying shrinkage crack due to increased water content. Expanding the scope of additives so as to use the right materials in the right places could exploit the potential effects of additives in terms of durability. Some recent researches on low-carbon blended cement are based on the premise that a similar level of “strength development” to that of OPC is achieved. However, if cement with improved performance such as durability is accepted even if it has a delay in strength development as compared to OPC, its use as additives and admixtures could be expanded.

Furthermore, with little prospect of an increase in domestic demand for cement, it is necessary to develop clinker that allows for maintaining or increasing the amount of waste and by-products treated as well as expanding the use of additives.

(2) Promotion of use as admixtures in terms of supply

When admixtures such as blast-furnace slag and fly ash are supplied solely without being premixed into cement, suppliers of admixtures need to take shipping measures into consideration, and establishing a distribution system is essential to achieve widespread use across the country. Under the circumstances where the domestic cement demand is below half of that in peak periods, some service stations (SS) for cement supply are closed or used for different purposes. Utilizing these stations effectively allows for supplying admixtures exclusively. In addition, it is very difficult to supply admixtures at any desired blending rate, but if they are blended at and supplied from service stations, it is possible to do so depending on the intended use. In that case, however, there are many issues to be addressed, such as responsibilities with regard to quality and traceability.

The quality of fly ash varies widely depending on power plants where it is generated and types of coal used in power plants. A major issue is that the amount of unburned carbon in fly ash greatly affects air-entraining of concrete. In general, fly ash is supplied from certain power plants, but recently, some attempts have been made where coal ash generated from multiple power plants is brought together to an ash center to be homogenized and shipped. This system enables users to always obtain fly ash with a constant level of quality, while providing an ash center with a constant amount of fly ash, allowing for planned supply depending on demand. Establishing such centers nationwide ensures the quality of fly ash and stability in supply.

3.2.2 Construction that supports proactive use of admixtures

Concrete containing high levels of admixtures in replacement with cement as a binder generates a smaller amount of heat, and is suitable for mass concrete structures. In addition, utilizing the effects of various admixtures allows for development of environmentally-friendly concrete that can control alkali-silica reactions and the permeability of chloride ion, and improve freezing and thawing resistance.

On the other hand, however, such concrete is susceptible to environmental and construction conditions after it is freshly mixed and cured as compared to ordinary concrete. In particular, it is unavoidable that admixtures made from by-products have a lower degree of activity than that of cement, and variability in quality. There are many things to keep in mind in each construction process from transport to placing, compacting, finishing and curing. The following are proposals on ways of construction that support proactive use of admixtures:

(1) Defining workability in consideration of construction conditions

In general, concrete containing high levels of admixtures requires a smaller water content to achieve the same level of fluidity as that of concrete without admixtures. In such concrete, however, fluidity tends to decline over time while viscosity increases. Therefore, methods are needed to address the decline in fluidity caused by pressurization during loading, unloading and pumping. In addition, it is important to define workability on the understanding that a difference in viscosity makes a difference in vibration compaction characteristics. Recently, admixtures that control changes in fluidity over time have been put to practical use, and can be used as a material measure as necessary.

(2) Defining finishing time in consideration of bleeding and stiffening

Concrete containing high levels of admixtures tends to take more time for setting as compared to concrete without admixtures. In general, delay in setting results in increase of bleeding, or more specifically, more water is generated on a crown of structure. If a concrete surface is finished at an earlier timing, it may cause settlement crack after finishing.

On the other hand, the use of admixtures at high levels may increase water retention of concrete and cause little bleeding. An extremely low level of bleeding causes loss of moisture from a crown as in the case of high-strength concrete, resulting in a stiffened surface that is difficult to be finished evenly.

As mentioned above, the state of a finished surface varies depending on water retention and setting characteristics when admixtures are used in concrete at high levels. Therefore, it is important to identify the best time for finishing. When a surface becomes stiffened because of little bleeding, application of membrane curing compounds is effective to keep a surface from drying out as in the case of high-strength concrete.

(3) Measures to maintain wet conditions, and establishing an evaluation method for porosity

Ordinary concrete has a defined wet curing time depending on temperature conditions. When admixtures are used in concrete at high levels, it is essential to have a longer wet curing time in order to achieve the same level of strength after curing as that of ordinary concrete.

To ensure the required performance of concrete structures, it is necessary to define the scope of curing, wet conditions and period. To this end, it is advisable to evaluate porosity and other properties qualitatively, and clarify a correlation with conventional curing specifications.

Concrete containing admixtures at high levels usually exhibits low strength at an early age. In addition, it is demonstrated that exposure to dry conditions may have adverse effects on long-term strength development. It is essential to take any engineering measures to maintain wet conditions, such as by maintaining a sealed curing condition and spraying water proactively.

4. Conclusion

Concrete is a highly durable and relatively environmentally-friendly construction material that ensures safety and security from a long-term perspective, although it is accompanied with a large volume of CO_2 emissions at an initial stage of use. Many types of industrial by-products have been used as admixtures (or additives) that serve as a binder in concrete. However, it is also true that drawbacks of by-products such as variable quality, as well as regional and construction constraints, have hindered their proactive use. It is desirable that the use of such admixtures will be expanded in terms of the effects on the global environment and effective use of resources.

The Committee held a “Symposium on Extension of Usage of Mineral Admixtures in Concrete” [8)] on December 26, 2011, the first year of the activity period, with the aim of broadly collecting and exchanging information and opinions, and reflecting them in the Committee’s activity. At the symposium, 27 papers that had been solicited from the general public were presented, and participants had a meaningful exchange of opinions.

References

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