Committee Report: JCI- TC174A

Technical Committee on Reasonable Test Method for Evaluation of Concrete Performances based on their Principles

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Abstract

The members of this technical committee conducted a survey focusing on various methods for evaluating the performance of concrete, for the purpose of rationalizing and achieving labor savings with outdated test methods. The subjects of the survey included testing of concrete materials, fresh concrete, and hardened concrete. In surveying each subject, if there were materials or concrete properties requiring fresh evaluation, we organized them while also surveying the related evaluation methods, considering recent diversifications in concrete production.

Keywords: concrete making materials, fresh concrete, hardened concrete, test method, rationalization, labor-saving

1. Introduction

Various new materials have been used in concrete production. For example, new materials are being used for the aggregate (a component of concrete mix). To address environmental concerns and to develop concrete with new properties, river-derived aggregate is being replaced by crushed sand and stone, various metal smelting by-products, as well as recycled aggregate. Such new materials often have properties far different from previous materials; thus, it is sometimes difficult to apply existing quality test methods to them. The consistency of manufactured concrete ranges from highly stiff to having high fluidity, and the properties of fresh concrete vary depending on the use of superplasticizers and other admixtures. Progress has also been made in construction methods, and the properties sought for fresh concrete have been changing depending on these methods. This applies to hardened concrete as well. In addition to mechanical properties, permeability and surface concrete qualities have been investigated from the perspective of durability of concrete structures. Furthermore, efforts have been made to ascertain deterioration through non-destructive or micro-destructive testing of structures currently in use.

On the other hand, changes are also being made to ensure safe and environment-friendly testing of concrete. These include restrictions on dangerous tasks, handling of heavy objects, and use of hazardous chemicals during testing.

Against this background, in recent years, conventional test methods have been abolished and large-scale revisions implemented when reasonably justified. For example, revisions pertaining to specimen size reduction, based on relevant data, have been made to Japanese Industrial Standards (JIS). This stems from recent attitudes towards reducing the maximum size of coarse aggregate, having general mold, and reducing the load of examiner in the testing. This includes changes to the specimen size for splitting tensile strength testing in JIS A 1132: “Making specimens for strength testing of concrete.” In addition, JIS A 1141: “Test methods for particles floating in liquid with a density of 1.95 g/cm^3 contained in aggregate,” was abolished in 2015 as it does not be used equipment for transporting coal and lignite to transport aggregate in Japan, and as it is environmentally unsafe, considering the hazards of the highly concentrated zinc chloride solution used for the test.

Table 1: Members and working groups (WG)

Chairman: Atsushi Ueno (Tokyo Metropolitan University)	Vice-chairman: Shigeyuki Sogo (Near Future Concrete Association)	Advisor: Tokio Kuroi (Ashikaga University)
Material WG		
Chief Examiner: Yoshio Uchida (Japan Construction Method and Machinery Research Institute)		
Koji Horiguchi (Chuken Consultant)	Makoto Higaki (Flowric Co., Ltd., 2017)	Ryo Kishira (Taiheiyo Cement Corporation)
Masanao Arai (General Research Building Corporation of Japan)	Ryusuke Tamaishi (Kao Corporation, 2018)	Sho Hashizume (Zennama (until June 2018)
Fresh Concrete WG		
Chief Examiner: Shuzo Otsuka (Institute of Technologists)		
Takeshi Saito (Nihon University)	Kuniaki Sakurai (Obayashi Corporation)	Jun Liang (Taisei Coroporation)
Shinji Urano (Shimizu Coroporation)	Takao Chikada (Aso)	
Hardened Concrete WG		
Chief Examiner: Madoka Taniguchi (Hokkaido Research Organization)		
Shintaro Wakabayashi (Zenitaka Corporation, 2017)	Atsushi Kawamata (Tekken Corporation, 2018)	Susumu Yoshida (Civil Engineering Institute for Cold
Norikiyo Nakamura (Japan Testing Center for Construction Materials)	Akira Nonaka (Kumagai Gumi Co., Ltd.)	

The purpose of this technical committee was to organize test methods for concrete with regard to the following: the conformity of current test methods with the properties of recent materials, fresh concrete, and hardened concrete (logical conformity and labor-saving in the working environment); determining solutions to current issues; and the properties of materials or concrete tested in line with current circumstances.

The specific activities of the technical committee included surveying and organizing, which were achieved by three working groups (WGs): a “Material WG” for general material testing, a “Fresh Concrete WG” for fresh concrete testing, and a “Hardened Concrete WG” for hardened concrete testing. **Table 1** shows each WG and its members. In this report, we present a summary of the organizing performed by each WG.

2. Material WG

2.1 Subject properties or test methods

The Material WG members investigated of the test methods for mixing water, aggregate, cement, additives, and admixtures. Concrete materials were tested to determine their suitability, rather than to simply evaluate material performance; furthermore, test methods were established by product specifications, in addition to testing standards. Hence, the Material WG investigated not only testing standards, but also test methods established by certain product specifications. As a result, 31 current standards were investigated, a majority of which were JIS.

Today, river gravel or sand is rarely used in concrete production; concrete is mainly manufactured as an industrial product. Because of this, the focus is primarily on satisfying consumer quality demands, delivering consistent and improved quality, and producing the safest and most economical products possible. Further, it has been determined that concrete is tested as an industrial product, which means that performance and quality are guaranteed. **Figure 1** shows an example of the potential performance confirmation and quality management process of concrete materials as industrial products. When using certain materials, the materials are selected based on the test results which show performance of the actual concrete. However, it is believed that quality assurance is reasonable for methods suited to a given product. Several new types of concrete are being developed based on varying combinations of strength, liquidity, and materials used. Thus, it has been debated whether it is sufficient to simply assess the performance and material quality of concrete. It has been pointed out that, in future, there needs to be consideration about what constitutes proper quality assurance, including ensuring product quality, for techniques suited to different products.

We cite the long-term “OC cement bridge test results” of the Japan Cement Association in reports and highlight the unavoidable variations that arise in each test.

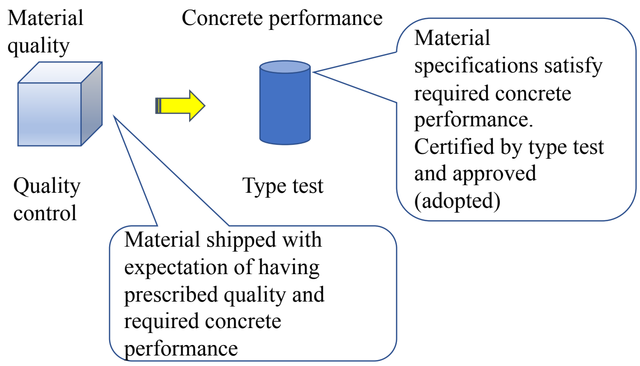

Fig. 1: Example of performance confirmation and quality assurance ideas

Table 2: Testing methods for aggregate strength and hardness

Nature and state of aggregate	Testing standard, test name	Test characteristics
Abrasion strength	Abrasion test for coarse aggregate due to JISA1121 Los Angeles test equipment	Measures amount of abrasion from impact with steel ball. Not applicable to lightweight aggregate for structures.
Strength	Crushing load test for JSCE-C505 high-strength fly ash artificial aggregate	Crushing is done per each aggregate particle. Spherical aggregate used.
	JISA5003 Stone	Prismatic specimens cut from rock to measure compression strength.
	JISA5006 rubble	
Crushing level	Estimation test method for coefficient of water absorption of regenerated coarse aggregate L in JIS A 5023 Appendix C	A steel container is filled with coarse aggregate, and static or load impact is used to measure the crushing percentage.
	Crushing level test for BS812-110 aggregate	
	Average impact resistance test for BS812-112 aggregate	
Hardness	Drill-type hardness test	Abrasion loss measured by pressing on a turntable.
	Moh's hardness	Hardness compared with or without scratches by scratching mineral of different hardness.
Estimated strength	Method of fixing and measuring multiple aggregate [7]	Strength measured with a fixed set of aggregate.

2.2 Issues with existing test methods and possible improvements

Here, we describe some of the investigation results for aggregate strength and hardness as examples of the discussions of the Material WG.

In high-strength concrete, the aggregate strength and hardness are assumed to influence the compressive strength and modulus of elasticity, although the mechanism of the relationship is not well known. The relationship between these properties can only be determined indirectly from the density and water absorption of the aggregate, which are assumed to be related to aggregate structure. There are no test methods capable of directly verifying quality indices of aggregate mechanical properties. Aggregate is selected for high-strength concrete based on verification tests by direct concrete tests. Hence, it is important to establish aggregate quality standards related to the mechanical properties of concrete, and test methods for evaluating aggregate quality.

Table 2 shows test methods for evaluating aggregate strength and hardness.

Fig. 2: Example of Los Angeles test equipment[1)]

JIS A 1121: "Abrasion test method for coarse aggregate using Los Angeles test equipment" is one of the current standards for aggregate strength and hardness. However, this test method evaluates only the abrasion resistance of aggregate and not its strength.

Fig. 3: Example of BS812-110 test device[2)]

In addition, as the tests specified in this standard are applicable to samples having only select particle sizes, the effectiveness of these tests remains questionable. However, JIS A 1121 Appendix A stipulates a test method for determining the amount of abrasion loss by using samples of all particle sizes. Hence, for materials similar to concrete, this is considered a reasonable test method.

Appendix C: "Test method for estimated values of water absorption of recycled coarse aggregate" of JIS A 5023: "Recycled aggregate concrete L" involves placing recycled coarse aggregate type L, having a particle size of 2.5 mm or more, into a steel container, crushing it using a 100-kN load, assuming the percentage of mass passing through a 2.5 mm sieve to be the crushing level, and then estimating the coefficient of water absorption from this crushing level. With this method, there are several factors to identify, including the applied load and the size of the sieve openings that the crushed aggregate passes through. However, this method is still considered effective for measuring the crushing level of various coarse aggregates. In addition, BS 812-110: "Method for determination of aggregate crushing value (ACV)" (aggregate crushing level test), stipulates a method in which a steel container such as that in **Figure 3**[2)] is filled with 10 to 14 mm coarse aggregate, which is then crushed by applying a 400-kN static load. The percentage of crushed particle mass is determined to be the crushing level.

2.3 New performance and test methods for contemporary concrete

When evaluating strength and hardness, coarse aggregate may be evaluated per particle or by size fraction, but fine aggregate may be difficult to evaluate if not in a full grading particle (also they are filled in a container) state. When evaluating hardness and strength by having grading distribution samples, particle size distribution and particle shape are ultimately assumed to have a major influence, and details of test conditions and quality reference values are required. It is hoped that there will be further studies accounting for aggregate strength and hardness in concrete mixing (preparation) and material selection, and selection of effective design properties such as tensile strength, bending strength, shear strength, and modulus of elasticity, along with compressive strength.

3. Fresh Concrete WG

3.1 Subject properties or test methods

The Fresh Concrete WG studied the test methods shown in **Table 3** from the perspective of rationalization and labor savings. The test methods were broadly divided here into JIS or related standards, and methods of evaluating fresh concrete. The former was divided into fresh concrete properties and mix proportion, and then the issues with each method and their possible solutions were summarized. For the latter, organizing was done for evaluation methods that could reasonably evaluate fresh concrete properties considered difficult to properly evaluate using individual test methods, owing to the combined influence of various factors, such as concrete compactibility. These properties are not covered by JIS or related test methods, and are associated with tasks such as pumping, placing, compaction, and finishing during concreting.

3.2 Issues with existing test methods and possible improvements

Here, we present an example of the results from test methods studied by the Fresh Concrete WG.

Table 3: Test methods for investigative subjects of fresh concrete WG

Types of test methods			Testing standards, etc.
Issues with test methods for properties of fresh concrete and methods for improvement	Test methods for deformability or liquidity without applying external force	Slump test	JIS A 1101
		Slump flow test	JIS A 1150
	Test methods for deformability or liquidity with external force applied	Test methods for stiff consistency concrete	JSCE-F 501 VB test JSCE-F 507 JSCE-F 508
		Test methods for wet consistency concrete	JCI-SQA1 JSCE-F 514 JSCE-F 511 JSCE-F 701
	Test methods for pumpability	Pressure bleeding test	JSCE-F 502
		Evaluation test for deformability in fresh concrete	JSCE-F 509
	Test methods for initial physical properties of fresh concrete	Concrete temperature	JIS A 1156
		Bleeding	JIS A 1123
		Setting time	JIS A 1147
		Amount of adiabatic temperature rise	Japan Cement Association method
Issues with test methods for fresh concrete mixing (preparing) and methods for improvement		Mass of unit volume	JIS A 1156
		Water content	ZKT-210 ZKT-211 CTM-1 to 7[3)]
		Air volume	JIS A 1116 JIS A 1118 JIS A 1128 JSCE-F 513
Evaluation methods for fresh concrete with combined influencing factors	Pumping		–
	Placing and compaction	Segregation	–
		Compactibility	–
	Finishing		–

(1) Pressure bleeding test

1) Test method issues

Pressure bleed testing is based on concrete flow mechanisms in pipes, where the formation of a lubricant film from water separation improves pumpability. The extent of water vaporization from concrete samples in a container, when a constant pressure is applied to the container, is measured over a fixed period of time. This is set forth as the “Pressurized bleeding test method (draft)” in JSCE-F 502. Although there is no mention of evaluating pumpability, this test can still be used as an index when determining concrete pumpability because a suitable range for pumping is indicated by standard curves B and C, from the relationship between the time elapsed after pressurization and the extent of water vaporization[4)]. However, it is often difficult to properly evaluate pumpability for long-distance pumping (in which the pumping pressure is likely to increase significantly), under special conditions (such as height pumping), and for special types of concrete (such as highly fluidized or high-strength concrete).

2) Methods of improvement

When using pressure bleed testing to evaluate pumpability, new standard curves corresponding to special pumping conditions and concrete properties should be investigated. When the pumping pressure is high, the pressure applied to the container also increases; this is considered to be a method of measuring the extent of water vaporization. A more detailed insight into the correspondence between measured data (such as from concrete pumping experiments) and the results of JSCE-F 502 tests is needed.

(2) Concrete setting time test methods

1) Test method issues

Concrete setting time is generally tested using JIS A 1147: "Concrete setting time test method". In this test, mortar obtained by-wet screening concrete samples is tested. Starting and ending times are set according to the penetration resistance (3.5 N/mm^2 and 28.0 N/mm^2 for starting and ending times, respectively) determined by a penetration needle having a cross-sectional area between 12.5 and 100 mm^2. This test method is also used to establish the setting time when laying concrete in two or more layers so that it prevents cold joints, the standard being prior to the beginning of concrete setting in the bottom layer. However, recent multifaceted studies suggest that the overlapping needs to be completed in considerably less time than the aforementioned starting time[5)] and prior to the penetration resistance of the bottom layer reaching 0.07 to 1.05 N/mm^2. In addition, meteorological conditions during the actual placing of the concrete sometimes diverge from JIS A 1147 test conditions; hence, the test results may not be entirely reliable.

2) Methods of improvement

If JIS A 1147 is used as an index to prevent the formation of cold joints, then additional steps, such as making the cross-sectional area of the penetration needle 200 mm^2 (as shown in ASTM C-403), need to be taken in order to achieve a penetration resistance of 0.07 to 1.05 N/mm^2. It is also desirable to use additional test methods that can determine the safety of and reflect actual construction conditions.

3.3 New performance and test methods for contemporary concrete

Here, we present a summary of the investigation results of surface finish, among the "Evaluation methods for fresh concrete with combined influencing factors" shown in **Table 3**.

Societies provide only qualitative specifications regarding the surface finish of concrete; presently, no quantitative evaluation indices exist. There have been attempts to qualitatively evaluate the surface finish of metal coatings and timing of finishing. For example, surface finishes of metal coatings are evaluated according to the relationship between the upper surface of concrete and the degree of smoothness, using scanning test equipment with a mounted metal coating[6)]. There are also examples[8)] of investigating the applicability of the timing of metal coat finishing in construction work in Japan, based on the penetration resistance of needles, shown in ASTM C403[7)]. However, this is generally not used owing to the need for large equipment and the fact that there is little available data. Due to the complex relationships between concrete types, work conditions, meteorological conditions, and other factors and these forms of evaluation, a single uniform approach is difficult to develop. However, new test methods capable of quantitatively evaluating surface finish and timing of finishing are necessary.

4. Hardened Concrete WG

4.1 Subject properties or test methods

The Hardened Concrete WG summarized issues with various test methods for hardened concrete and proposed improvements from the perspective of labor savings (special attention was given to lighter test pieces). The test methods addressed were the ones in JIS or related standards, for obtaining the post-hardening physical properties; the methods covering product standards were excluded. In addition, this group used the results obtained by JCI technical committee that investigated several post-hardening physical properties.

The studied methods were divided into those testing basic properties and those testing durability-related properties. The basic properties were compressive strength, bending strength, tensile strength, static modulus of elasticity, dynamic modulus of elasticity, changes in length, air void systems, pore structure, air permeability and water permeability. The durability-related properties were chloride ion concentration, diffusion factor, accelerated carbonation test, neutralization depth, accelerated ASR test, and freeze–thaw resistance. Here, we focus on the freeze–thaw resistance, which is a durability-related property.

4.2 Issues with existing test methods and possible improvement

(1) Freeze-thaw resistance

Concrete deterioration due to freeze–thaw action is broadly divided into internal deterioration and surface deterioration (scaling); therefore, separate tests are required for these two types of deterioration. **Table 4** shows a comparison between the main freeze–thaw test standards.

Surveys have been conducted on concrete freeze–thaw tests by technical committee TC-065A of the Japan Concrete Institute: “Technical Committee on Methods of Evaluating Freeze-Thaw Resistance in Concrete.” Hereinafter, we present excerpted highlights of the test method for internal deterioration.

1) Issues with existing test methods

It is a standard measure to determine the freeze–thaw resistance of concrete to internal deterioration, according to JIS A 1148: “Method of freeze-thaw testing of concrete (Method A)”

Table 4: Comparison of main freeze-thaw tests and contents

Relevant items		JIS A 1148 Concrete freezing and thawing test method Method A (Freezing and thawing in water) Method B (Freezing in air and thawing in water)	ASTM C672 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals	RILEM CDF Recommendation of Capillary Suction, Deicing Agent and Freeze–Thaw Test
Purpose		Relative evaluation of interior deterioration	Screening evaluation	Screening evaluation
Specimen	Dimensions, test surface area	100 mm × 100 mm × 400 mm Prismatic specimen	0.045 m^2 or more (area of one test surface)	0.08 m^2 or more (total of all test surfaces)
	Specimen height (thickness)		75 mm or more	70–150 mm
	Required number of specimens	3 or more	2 or more	5 or more
	Surface subject to testing	All specimen surfaces	Placement upper surface	Placement side surface
Curing	Demolding age	1st day of aging	1st day of aging	1st day of aging
	Curing in water	27 days (by 28th day of aging)	13 days (by 14th day of aging)	6 days (by 7th day of aging)
	Curing in air	—	14 days (by 28th day of aging)	21 days (by 28th day of aging)
Freezing and thawing temperatures	Reference point	Specimen center temperature	Test chamber internal temperature (room temperature)	Test chamber internal temperature (brine solution)
	Minimum freezing temperature	-18 ± 3 °C	-18 ± 3 °C	-20 °C ± 0.5 °C
	Maximum thawing temperature	+5 ± 2 °C	+23 ± 3 °C, 45–55% R.H.	+20 °C ± 0.5 °C
Freezing and thawing times	Freezing holding time	Freezing process: 1 cyc. required time - thawing process	16–18 h	3 h
	Thawing holding time	Thawing process: 25% or more 1 cyc. required time (Method A) Thawing process: 20% or more 1 cyc. required time (Method B)	6–8 h	1 h
	Temperature transition time (gradient)	1/2 or more of the time required for each process	Transition through specimen movement	4 h (10K/1 h)
Freezing and thawing cycle count	Required time for 1 cycle	3–4 h	22–26 h	12 h
	Measurement cycle count	Measurements per minimum 36 cycles (Generally measurements per 30 cycles)	Measurements per 5, 10, 15, 25 cycles and thereafter, 25 cycles	Measurements per minimum 14 cycles (Measurements per 4–6 cycles recommended)
Test solution	Test solution	Tap water	Liquid calcium chloride (any acceptable)	Liquid sodium chloride (any acceptable)
	Temperature	—	4g/100 mL (any acceptable)	3% (any acceptable)
	Pre-test water absorption	None in order to start testing after curing in water	—	Implemented 7 days due to capillary infiltration
	Test solution supply method	All surfaces	Upper surface (submersion)	Lower surface (capillary water absorption)
Evaluation method	Evaluation item	Evaluation per relative dynamic modulus of elasticity and mass-decreasing rate	Evaluation according to visual rating	Evaluation according to amount of scaling
	Standard for evaluation cycle count	300 cycles	50 cycles	28 cycles
Other constraints on test implementation		・Difficulties in scaling evaluation according to mass-decreasing rate	・Test time required for 1 cycle per day	・ Strictest temperature control ・Examples of using JIS test equipment

(hereinafter, JIS A Method). However, this test method generally uses prismatic specimens having dimensions of 100 × 100 × 400 mm, which are relatively heavy compared to cylindrical specimens. Further, the test requires approximately three months from specimen preparation to obtaining results, and a significant amount of time and work is required for measurements in every cycle. Rationalization and labor saving are, thus, desirable for this test.

2) Methods of improvement

To rationalize the freeze–thaw testing based on the JIS A Method and achieve labor savings, specimen size reduction has been considered[9)]. The length of one side of a specimen cross section may be 75 mm when using coarse aggregate that fully passes through a 26.5 mm mesh sieve (maximum coarse aggregate size of smaller than 25 mm) for the JIS A Method. Automatic measurements of the dynamic modulus of elasticity, according to longitudinal and flexural vibrations (based on JIS A 1127: "Test methods for dynamic modulus of elasticity, dynamic shear modulus of elasticity, and dynamic Poisson's ratio in concrete using resonant vibrations"), are also possible. Thus, the use of RILEM CIF testing[10)] (hereinafter, the CIF Method), which is a one-sided freeze–thaw test method, has been investigated, to shorten the testing period. However, more data on the relationship between the test results from the JIS Method and CIF Method are needed.

5. Conclusion

The members of this group investigated and summarized the issues with existing test methods and their possible solutions. Furthermore, they determined the properties of concrete and other similar materials, considering rationalization of and achieving labor savings with concrete test methods, diversification in materials recently used in concrete production, expanding fresh concrete filings by changing cross sections, rebar arrangements, and construction methods, and diversifying the properties required for hardened concrete.

This paper introduces the results of these investigations. Please refer to the reports for detailed information. The members of this technical committee also made proposals for existing test methods not included in this paper, and they shall conduct a symposium in September 2019 to broadly discuss this study and the proposal of new test methods.

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