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GUIDELINES FOR CONSTRUCTION USING BLAST-FURNACE SLAG AGGREGATE CONCRETE

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ABSTRACT

These guidelines cover the general requirements for the construction of plain and reinforced concrete structures using blast-furnace slag aggregates or blast-furnace slag mixed fine aggregates. Blast-furnace slag mixed fine aggregates a mixture of blast-furnace slag fine aggregate and natural fine aggregate made to improve the particle size distribution as well as to reduce chloride content of sea sand, etc. A blast-furnace slag fine aggregate mixing ratio ranging from20 to 60% is standardized in these guidelines. The ratio can be ascertained by the Japan Society of Civil Engineers Standard "Test Method for Blast-Furnace slag Fine Aggregate Mixing Ratio in Blast-Furnace slag Mixed Fine Aggregate (Draft)."

Keywords: construction guidelines, storage and handling of aggregate, mix proportioning, concrete mixing and transportation, ready-mixed concrete, placement and curing, quality control and inspection, reinforced concrete, plain concrete, blast-furnace slag fine aggregate, blast-furnace slag coarse aggregate, blast-furnace slag mixed fine aggregate

PREFACE

Blast-furnace slag is a by-product of the pig iron manufacturing process. Conventionally, this slag was used mostly as aggregate in concrete and roads. The demand for fine particles in the raw materials of admixtures and portland blast-furnace slag cement has recently been increasing, and presently the total annual use of blast-furnace slag as fine and coarse concrete aggregate is about 1.5 million tons.

The quality of blast-furnace slag used for concrete aggregates was standardized into JIS (Japanese Industrial Standard) A 5011 for coarse aggregate in 1977and JIS A5012for fine aggregate in 1981, respectively. In response to this standardization, the Japan Society of Civil Engineers (JSCE) issued "Guidelines for Design and Construction Using Blast-furnace slag Coarse Aggregate Concrete (Draft)" in 1977and "Guidelines for Design and Construction with Concrete Using Blast-furnace slag Fine Aggregates (Draft)"in 1983 to provide standard methods of application for these aggregates. However, over the years since these documents were issued some of the guidelines have become out of touch with the present situation.

To bring these guidelines for blast-furnace slag aggregates up to date, the JSCE established the Blast-furnace Slag Aggregate Working Group in the Committee on High Quality Concrete, funded by the Nippon Slag Association. In the meantime, the above-mentioned Japanese standards were updated in October 1992 to integrate both standards for blast-furnace slag fine and coarse aggregates, and to add ferronickel-slag fine aggregates.

Based on experience with blast-furnace slag fine and coarse aggregates over the past ten years or so, as well as on the results of studies and investigations of the latest data such as durability results, the present situation has been reflected in the updates. In addition, the earlier two sets of guidelines have been integrated into this single document, and the word "Draft" removed from the title because of the vast experience with these types of concrete. Effective use of resources is now a major concern since the global environment must be taken into account, so the updating of these guidelines is well-timed.

Thanks are due to all members of the Committee on High Quality Concrete, Dr. Katsuro Kokubu, the leader of the Working Group, and members of the Blast-furnace slag Aggregate Working Group for their effort sin bringing these guidelines to completion.

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July 1993

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Test Method for Blast-furnace Slag Fine Aggregate Mixing Ratio in Blast-furnace slag Mixed Fine Aggregate (Draft)

CHAPTER 1 GENERAL

1.1 Scope

(1) These guidelines cover the general requirements for the construction of plain and reinforced concrete structures using blast-furnace slag aggregates and blast-furnace slag mixed fine aggregates.
(2) Issues not covered by these guidelines shall comply with the requirements of the Standard Specification for Design and Construction of Concrete Structures issued by the Japan Society of Civil Engineers.

[Commentary]

Concerning (1): Standard mixing ratios for blast-furnace slag fine aggregate in blast-furnace slag mixed fine aggregate range from 20 to 60%. If the ratio exceeds 60%, it needs to be ascertained by testing in advance that concrete of the specified quality can be obtained.

Two types of blast-furnace slag coarse aggregate are available: Type A with low specific gravity under oven-dry and high water absorption ratio, and Type B with high specific gravity under oven-dry and low water absorption ratio, Concrete made with Type B blast-furnace slag coarse aggregate has good strength development and durability. These guidelines assume use of Type B blast-furnace slag coarse aggregate. Type A blast-furnace slag coarse aggregate, although not specifically covered by these guidelines, maybe used when there is no need to consider the durability of the concrete of the concrete has a specified strength of less than 210kg/cm^2(21N/mm^2).

In cases where both coarse and fine blast-furnace slag aggregate s are simultaneously used as concrete aggregate, it shall be ascertained through tests that concrete of the specified quality can be obtained since there have been few commercial applications of this type of concrete.

1.2 Definition of terms

The technical terms used in this document are defined as below.

Blast-furnace slag fine aggregate is a type of fine aggregate manufactured by quenching molten slag produced in a blast furnace together with pig iron using water or air. The particle size is graded for use in concrete.

Blast-furnace slag mixed fine aggregate is a mixture of blast-furnace slag fine aggregate and ordinary fine aggregate, either blended in advance of concrete mixing or during concrete mixing.

Blast-furnace slag fine aggregate mixing ratio (BFS mixing ratio) refers to the absolute volume ratio of blast-furnace slag fine aggregate to the total volume of fine aggregate in a blast-furnace slag mixed fine aggregate, expressed as a percentage.

Blast-furnace slag coarse aggregate is a type of coarse aggregate manufactured by slowly cooling molten slag produced in a blast furnace together with pig iron. The particle size is graded for use in concrete.

Blast-furnace slag aggregate s include blast-furnace slag fine aggregate and blast-furnace slag coarse aggregate .

Blast-furnace slag fine aggregate concrete refers to a type of concrete in which the fine aggregate consists of blast-furnace slag fine aggregate or blast-furnace slag mixed fine aggregate.

Blast-furnace slag coarse aggregate concrete refers to a type of concrete in which all the coarse aggregate consists of blast-furnace slag coarse aggregate.

Blast-furnace slag aggregate concrete refers to both blast-furnace slag fine aggregate concrete as well as blast-furnace slag coarse aggregate concrete.

Ordinary aggregate concrete is a type of concrete in which all the he and coarse aggregate s are ordinary aggregates.

[Commentary]

Concerning blast-furnace slag mixed fine aggregate: In many applications, pre-mixed blast-furnace slag mixed fine aggregate is used. In other applications, ordinary fine aggregate and blast-furnace slag fine aggregate are weighed separately and brought together during concrete mixing. Accordingly, the aggregate used in both methods is referred to as blast-furnace slag mixed fine aggregate.

To meet current demand for mixed aggregates, and to improve the quality of ordinary fine aggregate s such as reduced chloride content and adjustment of particle size distribution by mixing, these guidelines also cover the use of blast-furnace slag fine aggregates.

Concerning blast-furnace slag fine aggregate mixing ration: The grading of an aggregate indicates the mix of fine and coarse particles, or the distribution of fine and coarse particles in the aggregate. In principle, it should be expressed in terms of the volume occupied by the aggregate of each particle size. However, in practice, it is usually expressed as a mass percentage based on the assumption that each size of particle has a constant specific gravity. Normally, when mixing fine aggregates of similar types but with different particle size distributions, the effects of specific gravity on the mixing ratio are not taken into consideration because there is only a minor difference in specific gravity. However, when calculating the particle size distribution of mixed fine aggregates of different types, and therefore with different specific gravities, it is necessary to adjust the ratio for each particle size after mixing to a specified distribution range in terms of volume. Accordingly, it is proper to express the mixing ratio in terms of absolute volume. Although in most cases the difference in specific gravity between blast-furnace slag fine aggregate and ordinary fine aggregate is small, these guidelines in principle adopt mixing ratios expressed in terms of absolute volume.

CHAPTER 2 QUALITY OF BLAST-FURNACESLAG AGGREGATE CONCRETE

2.1 General

(1) Blast-furnace slag aggregate concrete shall have uniform quality and suitable characteristics such as strength, durability, water-tightness, and reinforcing steel protection. It shall also have a workability suitable for concrete work during construction.
(2) Basically, blast-furnace slag aggregate concrete is used as AE concrete.

[Commentary]

Concerning (1) and (2): Blast-furnace slag fine aggregate concrete using blast-furnace slag mixed fine aggregate at a BFS mixing ratio raging of 20 to 60% may be handled as a concrete with almost the same qualities as concrete using an ordinary aggregate.

In general, blast-furnace slag aggregate concrete is used as an AE (air-entrained) concrete; an appropriate amount of air is needed to improve the workability and other properties of the concrete.

2.2 Strength

(1) Standard strength of blast-furnace slag aggregate concrete shall be based on test data at the age of 28 days.
(2) Compression, tension, and bending tests for the concrete shall comply with the requirements of JIS A 1108, JIS A 1113, and JIS A 1106, respectively, and specimens shall be prepared according to JISA1132.

2.3 Limit of chloride content

(1) The chloride content of blast-furnace slag aggregate concrete shall be expressed in terms of the total number of chloride ions in the concrete.
(2) The standard total of chloride ions in blast-furnace slag aggregate concrete shall not exceed 0.30 kg/m^3during concrete mixing.

CHAPTER 3 BLAST-FURNACE SLAG AGGREGATES AND BLAST-FURNACE SLAG MIXED FINE AGGREGATES

3.1 General

Blast-furnace slag aggregate s and blast-furnace slag mixed fine aggregates shall be clean, hard, durable, of appropriate particle size and shape, and of uniform quality. The content of deleterious substances which could adversely affect the quality of concrete or the reinforcing steel shall be contained within the specified limits.

3.2 Blast-furnace slag fine aggregates

3.2.1 General

Blast-furnace slag fine aggregates shall meet the requirements of JIS A 5011.

[Commentary]: According to JIS A 501I "Slag Aggregate for Concrete, "blast-furnace slag fine aggregates are classified into four types by particle size. Each type of aggregate shall meet the quality requirements listed in Commentary Table 3.1.

Commentary Table 3.1 Quality of Blast-furnace Slag Fine Aggregates (JIS A 5011)

Item		Limit
Chemical composition	Calcium Oxide (%)	≤45.0
Specific gravity under oven-dry		≥2.5
Percentage water absorption (%)		≤3.5
Unit weight (kg/liter)		≥1.45

3.2.2 Particle size distribution

(1) The particle size distribution of blast-furnace slag fine aggregates shall fall within the limits given in Table 3.1. The method used for particle size analysis shall adhere to JISA 1102.

Table 3.1 Particle size distribution limits of blast-furnace slag fine aggregates

Nominal sieve size (mm) / Type	Amounts passing through sieve, percent by mass						
	10	5	2.5	1.2	0.6	0.3	0.15
5 mm BFS* fine aggregate	100	90-100	80-100	50- 90	25-65	10-35	2-15
2.5 mm BFS fine aggregate	100	95-100	85-100	60- 95	30-70	10-45	2-20
1.2 mm BFS fine aggregate	-	100	95-100	80-100	35-80	15-50	2-20
5-0.3 mm BFS fine aggregate	100	95-100	65-100	10- 70	0-40	0-15	0-10

*Blast-furnace slag

(2) The difference between the actual fineness modulus of the blast-furnace slag fine aggregate and that assumed in determining the concrete mix proportion shall not exceed 0.20.

[Commentary]

Concerning (1): The particle size distribution given for 5 mm blast-furnace slag fine aggregate is applicable when it is used alone and without other fine aggregates .The distributions given for other types are for use when they are mixed with ordinary fine aggregates.

Because blast-furnace slag fine aggregates contain many squarish particles, concrete with better workability and bleeding properties is obtained if more fine particles are included. In addition, since finer particles tend to have higher specific gravity, the mass percentage of finer particles increases even if the volume percentage is the same as that in an ordinary case. Therefore, as shown in Table3.1, the upper limit of mass percentage of a blast-furnace slag fine aggregate passing through a nominal 0.15 mm sieve is greater than the value of 10% specified in Section 3.4 "Fine Aggregates" of the Standard Specification for Design and Construction of Concrete Structures (Construction Edition).]

3.2.3 Limits of deleterious substances

The deleterious substance content of blast-furnace slag fine aggregates must not exceed the values listed in Table3.2. Chemical analyses and wet sieving tests shall comply with the requirements of Section 4.2 of JIS A 5011 and JIS A1103, respectively.

Table 3.2 Limits of deleterious substances (mass percent)

Substance	Maximum content
(1) Total sulfur (as S)	2.0
(2) Sulfur trioxide (as SO_3)	0.5
(3) Total iron (as FeO)	3.0
(4) Losses during wet sieving tests	7.0

[Commentary] Losses during wet sieving tests; Unlike clay and silt, the fine particles in blast-furnace slag fine aggregates are thought to have little effect on concrete quality. According to experimental results, in the case of concrete containing about 10% fine particles in the blast-furnace slag fine aggregate and with a properly specified mix proportion, fine particles have no adverse effect on workability and the amount of bleeding decreases only slightly. In addition, the fine material has positive effects, such as acting as a binder much like cement, as aging takes place. In the case of a very high fine particle content, however, the concrete becomes highly viscous. Furthermore, it not only becomes difficult to control the surface moisture level in the aggregate, but stable storage is also a problem during the warm months. Taking this into account, these guidelines specify a loss limit of 7% during a wet sieving test to ensure that concrete of stable quality can be obtained, although this is not specified in JIS A 5011 "Slag Aggregate for Concrete."

3.3 Blast-furnace slag mixed fine aggregates

3.3.1 General

(1) Blast-furnace slag fine aggregate for use in blast-furnace slag mixed he aggregate shall meet the requirements of Section 3.2.
(2) Ordinary fine aggregate to be used in blast-furnace slag mixed fine aggregate shall satisfy the requirements of the Standard Specification for Design and Construction of Concrete Structures, except, as regards the requirements for particle size distribution and chloride content.
(3) Blast-furnace slag mixed fine aggregate shall be prepared by uniformly mixing the blast-furnace slag fine aggregate and the ordinary fine aggregate .It shall in principle comply with the requirements of the Standard Specification for Design and Construction of Concrete Structures.

[Commentary]

Concerning (3): The chloride content of blast-furnace slag mixed fine aggregate shall meet the specifications of Section 3.4 "Fine Aggregates" of the Standard Specification for Design and Construction of Concrete Structures (Construction Edition).

The test method for chloride content shall comply with the requirements of the JSCE standard "Method of Test for Chloride Content of Sea Sand (Titration Method)."

The durability of blast-furnace slag mixed fine aggregate does not need to be considered

separately, aside from the question of chemical stability, if the blast-furnace slag fine aggregate and the ordinary fine aggregate meet the quality specifications of (1) and (2), respectively.

Concerning chemical stability, a blast-furnace slag fine aggregate may be regarded as safe if used alone, since blast-furnace slag aggregates do not take part in the alkali-aggregate reaction. If it is thought that the ordinary fine aggregate to be mixed with it is harmful, the blast-furnace slag mixed fine aggregate may not necessary to safe because of the PECIMUM effects of ordinary fine aggregates. In this case, it is necessary to check the safety of the blast-furnace slag mixed fine aggregate by carrying out tests in accordance with Attachment 7 "Test Methods for Alkali-silica Reaction in Aggregates (Chemical Method)" and Attachment 8 "Test Methods for Alkali-silica Reaction for Aggregates (Mortar-bar method)"of JIS A 5308. However, even aggregate s that have been judged as harmful or potentially harmful may be used if proper measures are taken to prevent adverse effects due to the alkali-aggregate reaction.

3.3.2 Particle size distribution

(1) The particle size distribution of blast-furnace slag mixed fine aggregates shall fall with in the limits given in Table 3.3.

Table 3.3 Standard particle size distribution for blast-furnace slag mixed fine aggregates

Nominal sieve size (mm)	Amounts passing through sieve, percent by volume	Nominal sieve size (mm)	Amounts passing through sieve, percent by volume
10	100	0.6	25-65
5	90-100	0.3	10-35
2.5	80-100	0.15	2-10[1)]
1.2	50-90		

1) If the blast-furnace slag fine aggregate accounts for more than 50% of the amount passing through a sieve of 0.15 mm in nominal size, the upper limit may be changed to 15%.

(2) If the difference between the actual fineness modulus of a blast-furnace slag fine aggregate and that assumed in determining the concrete mix proportion exceeds 0.20, the mix proportion shall be changed.

[Commentary]

Concerning (1): Since the particle size distribution of a blast-furnace slag mixed fine aggregate needs to be expressed in terms of absolute volume, as stated in Commentary 1.2, the particle size distribution in Table3.3 are expressed as amounts passing through each sieve in volume percent.

When the particle size distribution is adjusted by mixing blast-furnace slag fine aggregate with ordinary fine aggregate, the BFS mixing ratio shall be determined such that the particle size distribution falls within the ranges specified in Table3.3, or a fineness modulus from approximately 2.6 to 2.8.

In Section 3.4 "Fine Aggregates "of the Standard Specification for Design and Construction of concrete structures (Construction Edition), the upper limit for the volume percentage passing through a nominal 0.15 mm sieve is specified as 10%. However, for the same reasons given in

Commentary 3.2.2, this upper limit may be increased to 15% if the blast-furnace slag fine aggregate accounts for more than 50% of the total passing through a sieve of 0.15 mm in nominal size.

3.4 Blast-furnace slag coarse aggregates

3.4.1 General

Blast-furnace slag coarse aggregate shall meet the requirements for Type B aggregates as specified by JIS A 5011.

[Commentary]: Commentary Table 3.2 below shows the specifications for blast-furnace slag coarse aggregate specified in JIS A 5011"Slag Aggregate for Concrete."

Commentary Table 3.2 Types of blast-furnace slag coarse aggregate (JIS A 5011)

Types	Specific gravity under oven-dry	Percentage water absorption (%)	Unit weight (kg/l)
A	≥2.2	≤6.0	≥1.25
B	≥2.4	≤4.0	≥1.35

3.4.2 particle size distribution

(1) The particle size distribution of a blast-furnace slag coarse aggregate shall fall within the limits given in Table3.4. The method used for particle size analysis shall comply with JISA 1102.

Table 3.4 Particle size distribution limits of blast-furnace slag coarse aggregates

Nominal sieve size (mm) / Types	Amounts passing through sieve, percent by mass						
	50	40	25	20	15	10	5
BFS* coarse aggregate 4005	100	95-100	-	35-70	-	10-30	0-5
BFS coarse aggregate 4020	100	90-100	20-55	0-15	-	0-5	-
BFS coarse aggregate 2505	-	100	90-100	-	30-70	-	0-10
BFS coarse aggregate 2005	-	-	100	90-100	-	20-55	0-10
BFS coarse aggregate 1505	-	-	-	100	90-100	40-70	0-15

*Blast-furnace slag

3.4.3 Percentage of absolute volume

Blast-furnace slag coarse aggregates shall have good particle shape. The criterion used to judge the shape of particles in a blast-furnace slag coarse aggregate shall be the percentage of absolute volume. The test method shall comply with JISA 1104.

[Commentary]: The shape of particles in a blast-furnace slag coarse aggregate shall be judged in terms of the percentage of absolute volume after applying the rod compaction test method specified in JIS A 1104 "Test Methods for Unit Weight and Percentage of Absolute Volume of Aggregates."

3.4.4 Limits of deleterious substances

The criteria for judging the deleterious substance content of a blast-furnace slag coarse aggregate, and the relevant limits, are given in Table 3.5. The methods of chemical analysis, immersion testing, ultraviolet (360.0mm) exposure testing, and wet sieving testing shall comply with the requirements of Section 4.2 of JIS A 5011, Section 4.6 of JIS A 5011, Section 4.7 of JIS A 5011, and JIS A 1103, respectively.

Table 3.5 Deleterious substances: criteria and limits

Items	Maximum content (mass percent) and criteria
(1) Calcium oxide (as CaO)	45.0
(2) Total sulfur (as S)	2.0
(3) Sulfur trioxide (as SO_3)	0.5
(4) Total iron (as FeO)	3.0
(5) Immersion test	Shall be free from cracking, decomposition, slurry, and powdering
(6) Ultraviolet (360.0 nm) exposure test	Shall not emit light, or shall emit uniform purple light
(7) Loss during wet sieving test	5.0

[Commentary]: Losses during wet sieving tests: No specification for losses during a wet sieving test is given in JIS A 5011 "Slag Aggregate for Concrete." According to experiments, in the case of concrete containing not more than about 7%fine particles in the blast-furnace slag coarse aggregate, the fine particles have no adverse effect on properties such as workability, strength, durability, water-tightness, and drying shrinkage volume change; in fact, they often lead to improved results. In order to guarantee stable quality of the blast-furnace slag coarse aggregate, these guidelines specify a loss rate of 5% during the wet sieving test.

A 35% abrasion loss in blast-furnace slag coarse aggregate is acceptable when applied to concrete for pavements.

3.5 Storage and Handling

3.5.1 General

(1) Blast-furnace slag aggregates and blast-furnace slag mixed fine aggregates of different types and particle distributions shall be stored separately with partitions between types and particle size distributions.

(2) Blast-furnace slag aggregates and blast-furnace slag mixed fine aggregates shall be unloaded, stored, and handled carefully using equipment and facilities designed for the task so as to prevent particles from segregation according to size and becoming contaminated with foreign matter.

(3) Storage facilities for blast furnace slag aggregates and blast-furnace slag mixed fine aggregates shall be of suitable capacity and be equipped with appropriate drainage systems to maintain a constant surface moisture content.

3.5.2 Blast-furnace slag fine aggregates

Unmixed or pure blast-furnace slag fine aggregate s shall not been stored for long periods during the hot months.

[**Commentary**]: Because of slight hydraulicity, unmixed, pure blast-furnace slag fine aggregates are apt to consolidate after storage for long periods when the daily mean temperature exceeds 20 ^{o}C . This leads to changes in physical properties such as particle size distribution, specific gravity, and percentage water absorption. It has been ascertained, however, that this consolidation phenomenon can be held off for a considerable period if the aggregates are stored after uniform mixing with more than 20% of an ordinary fine aggregate. Other effective ways to prevent the consolidation of blast-furnace slag fine aggregate s are, for instance, to stack them in small lots to allow regular turning over with a **shovel dozer** or to spray them with consolidation inhibitors which do not affect the quality and mix proportion of the concrete before storage.

3.5.3 Blast-furnace slag mixed fine aggregates

Blast-furnace slag mixed fine aggregates shall be prepared by uniformly mixing blast-furnace slag fine aggregate with ordinary fine aggregate using an appropriate method.

[Commentary]: Two methods are available for mixing blast-furnace slag fine aggregate with ordinary fine aggregate: one is to mix them with together in the concrete mixer during concrete mixing; the other is to mix them in advance of use.

In the former case, each aggregate is weighed separately and added to the concrete mixer during concrete mixing. This method is preferable in that it assures uniform mixing.

3.5.4 Blast-furnace slag coarse aggregates

Blast-furnace slag coarse aggregates shall be stored in facilities equipped with suitable sprinkler and drainage systems so as to uniformly maintain the specified moisture content.

[Commentary]: The absorption of water by blast-furnace slag coarse aggregates is greater than that of ordinary gravel and crushed stone. The amount of water absorbed is apt to increase with time.

When using a blast-furnace slag coarse aggregate, there is therefore variations in quality occurring during concrete mixing, transportation, or placement. Thus, it is important to ensure that the aggregate absorbs water by pre-wetting it.

CHAPTER 4 PROPORTIONING

4.1 General

The mix proportion of blast-furnace slag aggregate concrete shall be selected so that the unit

water requirement is minimized with in the range that satisfies the needs of strength, durability, water-tightness, and workability.

4.2 Water-cement Ratio

(1) If the water-cement ratio is to be determined on the basis of concrete compressive strength, it shall comply with the requirements of the Standard Specification for Design and Construction of Concrete Structures.
(2) If the water-cement ratio is to be determined on the basis of concrete frost damage resistance, it

Table 4.1 Maximum water-cement ratios for AE concrete on the basis of concrete frost damage resistance (%)

Structure exposure conditions / Climatic conditions / Cross section	Severe or frequent repetitive freezing and thawing		Not severe, rarely below freezing point	
	Thin[2)]	Ordinary	Thin[2)]	Ordinary
(1) Portions continuously or frequently saturated with water[1)]	55	60	55	65
(2) Ordinary exposure conditions other than (1)	60	65	60	65

shall be not more than the value given in Table4.1.
Notes:
1) Sections of water channels, water tanks, bridge abutments, retaining walls, and tunnel linings, etc. which are close to water or saturated with water, and portions of girders and floors, etc. which are well away from water but are saturated due to melting snow, drift ice, splashing, etc.
2) Sections of structures with cross sections not more than about20 cm in thickness

[Commentary]: The water-cement ratio of blast furnace slag fine aggregate concrete, if it is to be determined on the basis of water-tightness, shall comply with the requirements of Section 19.2 "water-cement Ratio of Water-tight Concrete" of the Standard Specification for Design and construction of Concrete Structures (Construction Edition), in the same manner as for ordinary aggregate concrete.

Since there have been few commercial applications of blast-furnace slag fine aggregate ,the water-cement ratio of reinforced concrete required to have chemical resistance or to be used in marine structures shall be determined by referring to Item (3) of Section4.3 "water-Cement Ration" and Section 22.3.1"Water-Cement Ratio of Marine Concrete "in the Standard Specification for Design and construction of Concrete Structures(Construction Edition). This will ensure that dense concrete is obtained.

4.3 Slump and Fine Aggregate Percentage

(1) The slump value of blast-furnace slag aggregate concrete shall be determined as low as possible within the range suitable for concrete work.
(2) The percentage of fine aggregate shall be determined through tests to ensure that the unit water

requirement is minimized within the range which yields the specified workability.

4.4 Air Content of AE Concrete

(1) The standard air content of blast-furnace slag aggregate concrete shall be 4 to 7% of concrete volume, depending on the maximum size of the coarse aggregate and other conditions.
(2) The test method for the air content of AE concrete shall comply with JISA 1116,JIS A 1118,or JIS A 1128.

[Commentary]
Concerning (2): Any of the test methods for air content (the mass method (JIS A 1116),the volume method (JIS A 1118),or the pressure method (JISA 1128))is applicable. Since blast-furnace slag coarse aggregates contain internal voids, an aggregate correction factor needs to be considered. This correction factor is 1 to2 % larger than that used in the case of ordinary coarse aggregates.

4.5 Indicating the Mix Proportion

The mix proportion shall be reported as in Table 4.2.

Table 4.2 Mix proportion table

Maximum coarse aggregate size (mm)	Slump range (cm)	Air content range (%)	Water-cement ratio[1] W/C (%)	Fine aggregate percentage (%)	Quantity of material per unit volume of concrete (kg/m^3)						
					Water W	Cement C	Admixture F	Fine aggregate S[2]		Coarse aggregate G ( )[3]		Chemical admixture[4]
								Ordinary fine aggregate	Blast-furnace slag fine aggregate	mm to mm	mm to mm	
								(%)				

Table 4.2 Mix proportion table

Notes:
1) The water-cement ratio shall be replaced by the water-binder ratio if using admixtures with pozzolanic reactivity and latent hydraulicity.
2) When using a blast-furnace slag mixed fine aggregate, enter the unit quantities of ordinary fine aggregate and blast-furnace slag fine aggregate into the upper columns respectively. Alternatively, enter the unit quantity of blast-furnace slag mixed he aggregate into the lower column and the BFS mixing ratio into the parentheses.
3) When using a blast-furnace slag coarse aggregate ,enter the word BFG into the parentheses.
4) Chemical admixture consumption shall be expressed in ml/m^{3}or g/m^3, before dilution and/or dissolution.

CHAPTER 5 CONCRETE MIXING AND TRANSPORTATION

5.1 Concrete Mixing

(1) The order in which materials are fed into the concrete mixer shall be properly determined in advance.
(2) The appropriate mixing time shall be determined through tests.

5.2 Transporting

Suitable methods of transportation which minimize variations in quality and prevent the segregation of materials shall be used when transporting blast-furnace slag aggregate concrete .

[Commentary]: In the case of transporting blast-furnace slag coarse aggregate concrete using a concrete pump, blast-furnace slag coarse aggregate s hall be pre-wetted before concrete mixing. It is necessary to check its workability and variations in quality in advance.

CHAPTER 6 READY-MIXED CONCRETE

6.1 General

Ready-mixed concrete shall comply with the requirements of JISA5308.

CHAPTER 7 CONCRETE PLACEMENT AND CURING

7.1 Placement and consolidation

(1) Proper methods of placement which minimize material segregation shall be used when placing blast-furnace slag aggregate concrete.
(2) Blast-furnace slag aggregate concrete shall be fully consolidated immediately after placement. For consolidation, use of an insertion-type vibrator is recommended.

7.2 Curing

To ensure proper development of characteristics such as strength, durability, and water-tightness, blast-furnace slag aggregate concrete shall be fully cured after placement for a predetermined period at the correct temperature and humidity level.

CHAPTER 8 QUALITY CONTROL AND INSPECTION

8.1 General

The quality control and inspection of blast-furnace slag aggregate concrete shall comply with the requirements of the Standard Specification for Design and Construction of Concrete Structures.

[Commentary]: Blast-furnace slag mixed fine aggregates: When the components of a blast-furnace slag mixed fine aggregate are to be added to the concrete mixer during concrete mixing, quality can be ensured by storing and controlling the quality of the blast-furnace slag fine aggregate and the ordinary fine aggregate separately.

In the case of premixed blast-furnace slag mixed fine aggregate, quality control shall be maintained by the use of test certificates before and after aggregate premixing.

The BFS mixing ratio and uniformity of mixing may be ascertained by conducting tests in accordance with the JSCE standard "Test Method for Blast-furnace slag Fine Aggregate Mixing Ratio in Blast-furnace slag Mixed Fine Aggregate (Draft),"if necessary.

CHAPTER 9 GENRAL REQUIRMENTS FOR DESIGN AND CALCULATION

9.1 General

Design and calculations shall be comply with the requirements of the Standard Specification for Design and Construction of Concrete Structures (Design Edition).

ATTACHMENT:
Test Method for Blast-furnace slag Fine Aggregate Mixing Ratio in
Blast-furnace slag Mixed Fine Aggregate (Draft)

1. Scope

This standard specifies the test method to be used in determining the mixing ratio of blast-furnace slag fine aggregate in a blast-furnace slag mixed fine aggregate. (1)(2)

Notes:
(1) This standard is not applicable to blast-furnace slag mixed fine aggregates which contain ordinary fine aggregates high in calcium.
(2) This is applicable when samples of both the blast-furnace slag fine aggregate and the ordinary fine aggregate, which have been used to make the blast-furnace slag mixed fine aggregate, are available.

2. Test equipment and reagents

2.1 The test equipment needed for sampling and preparation is as follows:
(1) A dryer capable of maintaining a temperature of 105 ± 5 ^{o}C for long periods
(2) A vibrating mill to be used as a pulverize
(3) A sieve of 75 mm in a nominal mesh size (75mm openings) as specified in JIS Z 8801 "Standard Sieves"

2.2 The test equipment and reagents needed for analysis are as follows:

(1) A balance capable of weighing about 100g with a reciprocal sensitivity of 0.1 mg
(2) A 500 ml beaker as specified by JIS R 3503 "Glass Equipment for Chemical Analysis"
(3) A magnetic stirrer to be used as a mixer
(4) Type 5 B filter papers as specified by JIS P 3801 "Filters for Chemical Analysis"
(5) A melting pot as specified by JIS H 6201"Platinum Melting Pot for Chemical Analysis"
(6) A gas heater, gas burner, or electric heater suitable for use as a heating unit
(7) A thermostatic electric furnace capable of maintaining a temperature of 1000 ± 10 ^{o}C for longer than 30 minutes
(8) A desiccator as specified by JIS R 3503 or an equivalent container, containing moisture absorbents such as silica gel or calcium chloride
(9) Water purified by a distillation or ion-exchange method, or purified by a combination of reverse osmosis, distillation, and ion-exchange methods
(10) Premier grade hydrochloric acid as specified by JIS K 8180 "Hydrochloric Acid (Reagents)"

3. Sampling and preparation

3.1 Sampling
Take a typical sample. Reduce it to a predetermined volume by a quartering method or using a sample splitter. Dry the sample at 100-110 ^{o}C using a dryer so that it reaches a constant weight of about 200 g after drying. Store it in a desiccator if not prepared for testing soon.
3.2 Preparation

Reduce the sample further to about10g. Pulverize it in a vibrating mill. Pass it through a sieve to obtain particles finer than 75 μm . Store the result in a desiccator if not used for analysis soon.

4. Analytical method

4.1 General analytical procedures shall comply with the requirements of JIS K 0050 "General Requirements for Chemical Analysis."

4.2 Dissolution test using hydrochloric acid

(1) Weigh about 1 g of the sample prepared in Section 3.2 in a dry 500 ml beaker to an accuracy of 0.1 mg.
(2) Add 200ml of hydrochloric solution (1+20), prepared by adding water to the hydrochloric acid, to the sample. Stir the resulting solution with a magnetic stirrer for one minute. For three hours afterwards, stir the solution for one minute every hour. After completing stirring, allow the solution to settle for 24hours.
(3) Filter the solution prepared in (2) through a filter paper. After filtration, rinse out any solution remaining in the beaker through the filter paper eight times using warm water at 50 ^oC .
(4) Place the insoluble residue remaining after filtration together, with the filter paper, into a platinum melting pot. Dry using a heating unit, and then further heat the pot to incinerate the filter paper. Put the result into a thermostatic electric furnace and maintain it at a temperature of 1000 ± 10 ^oC for 30 minutes, then place it in a desiccator for radiative cooling.
(5) After radiative cooling, weigh the residues together with the platinum melting pot to an accuracy of 0.1 mg. Obtain the weight of insoluble residues in the sample by deducting the weight of the platinum melting pot[3)] from the measured value. Calculate the insoluble residue ratio using the following equation:

Insoluble residue ratio= (weight of insoluble residues/weight measured in (1)) $\times$ 100(%)

Note (3):
weigh the platinum melting pot in advance. Heat the pot in a thermostatic electric furnace for 30 minutes at a temperature of 1000 ± 10 ^oC and then allow it to cool in a desiccator before weighing it.

5. Calculating blast-furnace slag fine aggregate mixing ratio

5.1 Using the calibration curve obtained in Section6 below, find the ratio of blast-furnace slag fine aggregate corresponding to the insoluble residue ratio prepared in Section 4.2 (5).

5.2 Carry out this measurement procedure twice for samples taken simultaneously and obtain an average value.

6. Preparing a calibration curve

Prepare samples with blast-furnace slag fine aggregate mixing ratios of 25%, 50%, and 75% using the same ordinary fine aggregate and blast-furnace slag fine aggregate as used in the blast-furnace slag mixed fine aggregate. Obtain insoluble residue ratios in accordance with the

procedure described in Sections3 and 4. Draw a calibration curve expressing the relationship between the ratios of insoluble residue and blast-furnace slag fine aggregate mixing ratios.

7. Accuracy

The difference between two measurements of blast-furnace slag fine aggregate mixing ratio shall not exceed 5%. Conduct the test again if the difference exceeds 5%.

8. Reporting

When making a report, the following details shall be given:

(1) Type and origin of ordinary fine aggregate used in the blast-furnace slag mixed fine aggregate
(2) Type and manufacturer's name of blast-furnace slag fine aggregate used in the blast-furnace slag mixed fine aggregate
(3) Location and date of sampling
(4) Blast furnace slag fine aggregate mixing ratio (two measured values and the average)
(5) Place of analysis