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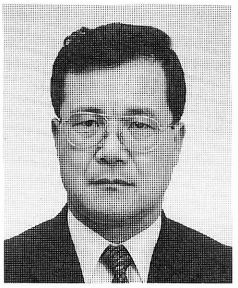
RECOMMENDATION FOR CONSTRUCTION OF CONCRETE CONTAINING GROUND GRANULATED BLAST-FURNACE SLAG AS AN ADMIXTURE

(Abridged translation from the CONCRETE LIBRARY No.86 published by JSCE, June 1996)

JSCE Research Subcommittee on Recommendation for Construction of Concrete Containing Ground Granulated Blast-Furnace Slag as an Admixture

Shinichi NUMATA, Chairman



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Revised Recommendation for Construction of Concrete Containing Ground Granulated Blast-furnace Slag as an Admixture of Recommendation for Design and Construction of Concrete Containing Ground Granulated Blast-furnace Slag as an Admixture which had been drafted at 1988 in Japan is presented. The replacement ratio of ground slag covered by this Recommendation is in the range equivalent to replacing 30% to 70% of portland cement. Three types of ground slag by the specific surface : ground slag 4000 (with a specific surface of 3000 to 5000 cm^2/g), ground slag 6000 (5000 to 7000 cm^2/g), and ground slag 8000 (7000 to 10000 cm^2/g) are specified according to JIS A 6206 (Ground granulated blast-furnace slag for use in concrete).

Keywords : recommendation, ground granulated blast-furnace slag, mineral admixture, concrete construction

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PREFACE

These Recommendations are a revision of the Recommendations for Design and Construction of Concrete Containing Ground Granulated Blast-furnace Slag as an Admixture (Draft) contained in the Concrete Library No. 63 published in 1988, and is based on state of the art technical information to adapt to JIS A 6206 (Ground granulated blast-furnace slag for use in concrete) established in March 1995.

The Research Subcommittee on Recommendation for Construction of Concrete Containing Ground Granulated Blast-Furnace Slag as an Admixture, which commenced its activities in June 1994, spent 22 months to surveying the literature published in the last 10 years after the closure of the previous committee, and conducted several experiments on the ground granulated blast-furnace slag (hereafter referred to as ground slag) currently manufactured and the samples remaining from the previous committee to investigate the workability, strength developing properties, and other subjects. These results led to the revision of the Recommendations.

Regarding curing, the relationship between the changes in the type of ground slag, replacement ratio, or temperature conditions and the moist curing period was streamlined. It was also pointed out that exposure of concrete surfaces to sea water during the early curing period can cause leaching of calcium hydroxide required for hydration of ground slag from concrete, though limited to the thin surface layer. This tends to make the concrete surfaces vulnerable to deterioration due to frost damage.

Regarding carbonation, long-term data obtained from structures have revealed that concrete containing ground slag in place of up to around 50% of cement with a normal range of water-cement ratio for general civil structures can be treated practically the same as concrete containing no ground slag.

Regarding resistance to sulfate, the use of ground slag containing a certain percentage of gypsum is recommended. This was found to relate to the replacement ratio.

Though we pointed out autogenous shrinkage with a low water-binder ratio, we did not get to reporting specific countermeasures.

New test methods for the ground slag combined ratio and replacement ratio were added to the conventional methods using a mixed solution of salicylic acid, acetone, and methanol. The new methods are expedited methods using a mixed solution of EDTA and triethanolamine.

Seventy requirements in 18 chapters particularly needed are provided in this library for the case of applying concrete containing ground slag to civil structures. The library also contains a JSCE Standard (Test methods for combined ratio and replacement ratio of ground slag), as well as "Properties of concrete containing ground slag" and "Literature on ground slag" both compiled from the results of the literature survey and tests conducted by the previous and present subcommittees.

Concrete containing ground slag has only a short history in Japan with limited field experience and reliable data. Had there been more information, the expressions of some of the newly compiled sections of these recommendations would have been more definite and concrete. Needless to say, we hope that future study will resolve these problems.

Utilizing ground slag contributes a lot to saving energy and resources from the standpoint of the global environment. Moreover, the importance of ground slag in the development of concrete technology outweighs its environmental significance. We sincerely hope that these Recommendations will contribute to the sound dissemination of concrete containing ground slag as a mineral admixture.

Last but not least, I would like to express my gratitude to the members of the Subcommittee and Working Groups, particularly to Prof. Yukikazu Tsuji, Secretary-general of the Subcommittee and Vice Chairman of the Working Group, and Prof. Yasuhiko Yamamoto, Vice Chairman of the Working Group, for their great efforts, as well as to Prof. Shigeyoshi Nagataki, Chairman of the former Research Subcommittee on Recommendation for Design and Construction of Concrete Containing Ground Granulated Blast-Furnace Slag as an Admixture, and the members of the Concrete Committee for their assistance.

March 1996

Shinichi Numata
Chairman
Research Subcommittee on Recommendation for Construction of Concrete Containing Ground Granulated Blast-Furnace Slag as an Admixture

RECOMMENDATION FOR CONSTRUCTION OF CONCRETE CONTAINING GROUND GRANULATED BLAST-FURNACE SLAG AS AN ADMIXTURE

CONTENTS

CHAPTER 1 GENERAL

1.1 Scope

(1) These recommendations provide the general requirements for the construction of concrete structures made using concrete containing ground granulated blast-furnace slag (hereafter referred to as "ground slag") as a mineral admixture. As to matters not specified herein, the JSCE Standard Specification for Design and Construction of Concrete Structures (hereafter referred to as the "Standard Specification") shall apply.

(2) The replacement ratio of ground slag covered by these Recommendations shall normally be in the range equivalent to replacing 30% to 70% of portland cement.

[Commentary]

Regarding (1): These Recommendations specify the general requirements for the construction of concrete structures made using concrete containing ground slag which conforms to JIS A 6206 (Ground granulated blast-furnace slag for use in concrete). When using ground slag as a mineral admixture in concrete, full understanding should be paid to the method of use and the properties of concrete containing ground slag. A construction plan should then be formulated with thorough examination of the proportioning, production, and curing of such concrete to fulfill the purpose of using it, and the construction must be carried out according to the plan.

The quality of ground slag varies depending on its fineness and whether or not gypsum is added. JIS A 6206 specifies three types of ground slag by the specific surface: ground slag 4000 (with a specific surface of 3000 to 5000 cm^2/g), ground slag 6000 (5000 to 7000 cm^2/g), and ground slag 8000 (7000 to 10000 cm^2/g). It limits the addition of gypsum to a sulfur trioxide (SO_3) equivalent of not more than 4.0%. Concrete containing ground slag can be produced to have diversified properties depending on the method of use, as the differences in type and replacement ratio of ground slag lead to considerable differences in such properties as mixing, fresh concrete, hydration and exotherm, strength development and durability. Although this is an advantage of using ground slag, it can be a disadvantage in the event of inadequate selection of the type and replacement ratio, which can lead to nonconformity with the quality requirements or production of uneconomical concrete.

When using ground slag, ground slags 4000, 6000, or 8000 specified in JIS A 6206 should normally be used. Ground slag 4000 has an effect of reducing the temperature rise of concrete similarly to portland blast-furnace slag cement, and it is characterized by a higher effect produced by changing the replacement ratio and the type of cement to be used in combination. Ground slags 6000 and 8000 impart a high segregation resistance, including bleeding resistance, to concrete while ensuring the fluidity. They also improve the early strength development. They are therefore suitable for the cases where high early strength is required and for high strength concrete, as well as for superworkable concrete that particularly requires high fluidity and segregation resistance.

In the case of concrete covered by the present Recommendations, the Standard Specification [Design] may be referred to regarding matters related to structural design. However, when using ground slag for a special concrete out of the scope of the present Recommendations, when using ground slag not conforming to JIS, or when the replacement ratio is out of the range of 30% to 70%, detailed study should be carried out in advance for both the design and construction aspects with reference to the present Recommendations and the Standard Specification.

Regarding (2): With a replacement ratio of less than 30%, the effect of using ground slag may not become appreciable. With a replacement ratio exceeding 70%, great care is required in each stage, such as curing, and there have been few test results and field experience to refer to. For this reason, the present Recommendations, as a rule, cover the range equivalent to replacing 30% to 70% of portland cement. Nevertheless, there certainly have been examples of construction overseas with a replacement ratio of over 70% and some study reports in Japan. The present Recommendations therefore do not intend to restrict concreting with a replacement ratio exceeding 70%, provided that it is ascertained to be practicable with a sufficient reliability. The commentary for Section 3.3 gives the range of ground slag replacement ratio in the combination of blended cement.

1.2 Definitions

The definitions of certain terms used in these Recommendations are as follows:

Ground granulated blast-furnace slag (Ground slag): A material obtained by rapidly chilling with water of molten slag produced simultaneously with pig iron in a blast furnace, and then by drying and pulverizing with or without an addition of gypsum.

Blend ratio: The percent ratio of the mass of ground slag contained in ordinary portland or blended cement to the mass of the cement.

Combined ratio: The percent ratio of the total mass of ground slag added as a mineral admixture and ground slag preblended in ordinary portland or blended cement to the total mass of the binders.

Replacement ratio: The percent ratio of the mass of ground slag added as a mineral admixture to the total mass of the binders.

Activity index: The percent ratio of the compressive strength of test mortar containing ground slag at a replacement ratio of 50% to the compressive strength of reference mortar made using ordinary portland cement tested in accordance with the Appendix of JIS A 6206.

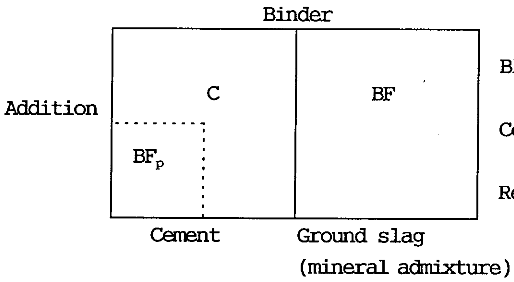
Fineness: The fineness of ground slag measured by the method in accordance with JIS A 6206. This is expressed in terms of specific surface (cm^2/g).

[Commentary]

Regarding ground slag: Blast-furnace slag is a byproduct in the production of pig iron in a blast furnace. It is roughly classified into two categories: crystalline air-cooled blast-furnace slag and vitreous granulated blast-furnace slag. Ground slag is obtained by pulverizing the latter with or without an addition of gypsum. The addition of gypsum is limited to a sulfur trioxide (SO_3) equivalent of not more than 4.0% by JIS A 6206 (Ground granulated blast-furnace slag for use in concrete).

Table C 1.2.1 Type and specific surface of ground slag

Type	Specific surface (cm^2/g)
Ground slag 4000	3,000 to less than 5,000
Ground slag 6000	5,000 to less than 7,000
Ground slag 8000	7,000 to less than 10,000



$$\text{Blend ratio} = \frac{BF_p}{C} \times 100\ (\%)$$

$$\text{Combined ratio} = \frac{BF_p + BF}{C+BF} \times 100\ (\%)$$

$$\text{Replacement ratio} = \frac{BF}{C+BF} \times 100\ (\%)$$

where C = mass of cement

BF_p = mass of ground slag contained in cement in advance as an addition

BF = mass of ground slag used as a mineral admixture

Fig. C 1.2.1 Definitions of blend ratio, combined ratio, and replacement ratio

JIS A 6206 specifies three types of ground slag according to the specific surface (see Table C 1.2.1).

Regarding blend ratio: Blend ratio refers to the ratio of the mass of ground slag contained in cement in advance (see Fig. C 1.2.1). JIS permits additions of up to 5% in total of blast-furnace slag, pozzolans, fly ash, and pulverized limestone for clinkering to ordinary portland cement, singly or in combination. Also, the blast-furnace slag contained in portland blast-furnace slag cement is specified to be more than 5% and not more than 30% for Type A, more than 30% and not more than 60% for Type B, and more than 60% and not more than 70% for Type C.

Regarding combined ratio: Combined ratio refers to the ratio of the total mass of ground slags added as a mineral admixture and preblended in cement as its constituent to the total mass of the binders (see Fig. C 1.2.1).

Regarding replacement ratio: Replacement ratio refers to the ratio of the mass of ground slag used as a mineral admixture to the total mass of the binders (see Fig. C 1.2.1).

Regarding activity index: Activity index refers to the degree of strength-developing property of ground slag, and is an important item of quality requirement indicating the performance of ground slag. For instance, a high activity at an age of 7 days indicates a high early strength and a high heat of hydration.

Activity index has a close correlation with the ratio of compressive strengths of concretes tested in the same way.

Regarding fineness: Fineness of ground slag has a profound effect on the properties of concrete. Among the various methods of evaluating fineness, JIS A 6206 adopts specific surface testing (Blaine Method).

CHAPTER 2 QUALITY OF CONCRETE CONTAINING GROUND SLAG AS A MINERAL ADMIXTURE

2.1 General

Concrete containing ground slag as a mineral admixture shall have workability suitable for the work and the required strength, durability, watertightness, resistance to cracking, and capability to protect reinforcing steel from corrosion when hardened with minimum variation in quality.

[Commentary]

The properties of concrete containing ground slag have some differences from those of concrete without it. When using concrete containing ground slag, such properties should be thoroughly grasped to obtain the required qualities with minimum variabilities.

2.2 Selection of type and replacement ratio of ground slag

The type and replacement ratio of ground slag shall be appropriately selected so as to attain the qualities of concrete required according to the purpose of using ground slag.

[Commentary]

Though the qualities of resulting concrete depend on the type and replacement ratio of ground slag, general uses of ground slag as a mineral admixture for concrete are (1) to reduce the temperature rise due to hydration heat, (2) to suppress alkali-silica reaction, and (3) to improve chemical resistance to actions of sulfate or sea water. Also, the application of ground slag to superworkable concrete is effective, as it improves the workability of concrete. Moreover, the use of ground slag 6000 or ground slag 8000 not only reduces the amount of bleeding water, but also increases the strength gain. High strength concrete can therefore be easily produced by using these types of ground slag.

The appropriate type and replacement ratio of ground slag to be used are naturally limited to certain ranges according to the purpose of use. Table C 2.2.2, which summarizes the past survey results, may be referred to when selecting the type and replacement ratio of ground slag for each purpose.

Table C 2.2.2 Type of ground slag and desirable ranges of replacement ratio

Purpose of use \ Type	Ground slag 4000	Ground slag 6000	Ground slag 8000
Reduce temperature rise due to hydration heat	50~70%	60~70%	60~70%
Suppress alkali-silica reaction	40~70%	40~70%	40~70%
Improve resistace to sulfates	50~70%	50~70%	50~70%
Improve chemical resistance to sea water (incl. salt damage)	45~55%	45~60%	45~70%
Give high fluidity	30~70%	30~70%	30~60%
Give high strength	—	30~50%	30~60%

Note: These values are for the case of replacing part of ordinary portland cement with ground slag.

2.3 Strength

(1) Generally, the strength of concrete containing ground slag as a mineral admixture shall be expressed by 28-day compressive strength of standard-cured specimens.

(2) In the case of pavement concrete, the strength shall generally be based on 28-day flexural strength of standard-cured specimens.

(3) In the case of dam concrete, the strength shall generally be based on 91-day compressive strength of standard-cured specimens.

[Commentary]

Regarding (1): When properly cured, concrete containing ground slag as a mineral admixture develops a higher compressive strength at 28 days and later than ordinary concrete without ground slag. It may therefore be considered unreasonable from an engineering standpoint to adopt 28-day compressive strength as the basis similarly to ordinary concrete without ground slag. However, 28-day compressive strength of standard-cured specimens was adopted as the basis for the strength of concrete for general structures, in consideration of the fact that it is also adopted for concrete made using portland blast-furnace slag cement having the same strength tendency and that the compressive strength gains of concrete containing ground slag widely vary depending on its type and replacement ratio.

Regarding (2): The strength and age of pavement concrete to be used as the basis were adopted in accordance with the Standard Specification [Pavement]. Certain types of pavement may be based on compressive strength.

Regarding (3): The strength and age of dam concrete to be used as the basis were adopted in accordance with the Standard Specification [Dam].

CHAPTER 3 MATERIALS

3.1 General

Materials to be used shall be of confirmed quality.

3.2 Ground slag

(1) Ground slag shall conform to JIS A 6206 as a rule.

(2) Ground slag to be used for dam concrete shall conform to the requirements of Section 14.2 of these Recommendations.

[Commentary]

Regarding (1): JIS A 6206 (Ground granulated blast-furnace slag for use in concrete) specifies the specific gravity, specific surface, activity index and flow value ratio of mortar, and chemical compositions as the qualities of ground slag. These quality requirements are intended for the application of ground slag to structures in general, as well as structures for which the concrete is required of high fluidity, strength, and durability. Accordingly, the present Recommendations observe JIS A 6206 and generally require to use ground slag conforming to it.

Regarding (2): When ground slag is used for the purpose of reducing the temperature rise as in the case of dam concrete, a better result may be obtained by the use of ground slag 4000 with a 7-day activity index lower than the specified limit. For this reason, such a deviation is permitted for dam concrete as stated in Chapter 14 (Dam Concrete) of the present Recommendations.

3.3 Cement

(1) Cement shall conform to JIS R 5210, and ordinary portland cement shall normally be used. When using high-early-strength portland cement or moderate-heat portland cement, the strength-developing properties and exotherm properties of resulting concretes shall be confirmed.

(2) When using portland blast-furnace slag cement, portland pozzolan cement, and portland fly ash cement conforming to JIS R 5211, JIS R 5212, and JIS R 5213, respectively, the methods of use shall be thoroughly examined.

[Commentary]

Regarding (1): The cement to be used is required, as standard practice, to be ordinary portland cement. This is because the properties of concrete made using ordinary portland cement partially replaced with ground slag can be predicted relatively easily from past study results and field experience. Ordinary portland cement may contain some blast-furnace slag, fly ash, or other additions up to 5%, but their effects are negligible for practical use.

High-early-strength portland cement is used in combination with ground slag 4000, in order to obtain an early strength comparable to the case of ordinary portland cement with no ground slag, or to ensure a high early strength in cold weather. Even in such a case, a high replacement ratio of ground slag 4000 may cause an early strength loss. It is therefore recommended that the early strength properties be ascertained by reliable data or by testing.

Moderate heat portland cement is used in combination with ground slag 4000 mostly to reduce the temperature rise of concrete. In such a case, an inadequate replacement ratio of ground slag may not only nullify its effect but also can even increase the temperature rise. Also, low curing temperature may significantly hamper the strength development. It is therefore necessary, when using moderate heat portland cement, to grasp the exotherm properties of concrete by testing in advance.

Regarding (2): When using blended cement, those conforming to JIS R 5211 (Portland blast-furnace slag cement), JIS R 5212 (Portland pozzolan cement), and JIS R 5213 (Portland fly ash cement) should be used. The use of such blended cements in combination with ground slag has been limited to a few exceptional instances.

When using blended cement, the replacement of ground slag in the cement may vary depending on the type and brand of the cement. It is therefore necessary to confirm in advance the kind of additive and its blend ratio of the cement by test reports, etc., in order to select an adequate replacement ratio of ground slag to obtain concrete with the required qualities.

The upper limit of ground slag replacement ratio when blended cement is to be used should be determined, so as to ensure the amount of portland cement for supplying hydroxide ions and calcium hydroxide sufficient for the additions, such as ground slag and fly ash, to act as binders. The replacement ratio of ground slag added as a mineral admixture is generally expressed as:

(1) In the case of portland blast-furnace slag cement

$$SR = \frac{R-S}{100-S} \times 100 \quad \text{(Eq. C 3.3.1)}$$

where SR = replacement ratio of ground slag (%)
R = combined ratio of ground slag in the binders (%)
S = blend ratio of ground slag preblended in the portland blast-furnace slag cement (%)

(2) In the case of portland fly ash cement and portland pozzolan cement

$$SR = R \quad \text{(Eq. C 3.3.2)}$$

When blended cement is to be used, the upper limit of ground slag added as a mineral admixture is determined on the basis of the maximum blend ratio specified in Section 1.1 (2) of the present Recommendations and current JIS for blended cement as follows:

(1) In the case of portland blast-furnace slag cement

$$RS_g \leqq \frac{70-S}{100-S} \times 100 \quad \text{(Eq. C 3.3.3)}$$

where RS_g = upper limit of ground slag replacement ratio (%)

(2) In the case of portland fly ash cement

If it is assumed that the upper limits of the portland cement component-fly ash ratio required for hydrating fly ash and portland cement component-ground slag ratio required for hydrating ground slag are 0.3 and 0.7, respectively, then

$$RS_g \leqq \frac{70(30-F)}{30-0.7F} \times 100 \cdots\cdots \text{(Eq. C 3.3.4)}$$

where F = blend ratio of fly ash preblended in portland fly ash cement (%)

However, hydration of portland fly ash cement partially replaced by ground slag has not yet been fully clarified. The present Recommendations, as a rule, adopt the following equation to be on the safe side as illustrated in Fig. C 3.3.1 (2).

$$\frac{F}{30}+\frac{RS_g}{70} \leqq 1 \quad \therefore \quad RS_g \leqq 70\left(1-\frac{F}{30}\right) \cdots\cdots \text{(Eq. C 3.3.5)}$$

When the amount of additive preblended in a blended cement are unknown, the maximum value specified in respective JIS should be adopted.

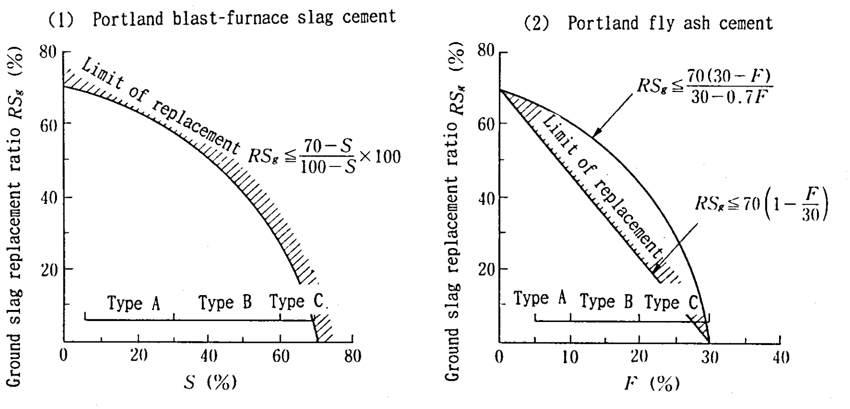


Fig. C 3.3.1 Limits of ground slag replacement ratio when blended cement is used

3.4 Admixtures

(1) Fly ash, expansive additives, and silica fume to be used shall conform to JIS A 6201, JIS A 6202, and JSCE-D 106, respectively.

(2) Chemical admixtures, corrosion inhibitors, superplasticizers, and admixtures for antiwashout underwater concrete to be used shall conform to JIS A 6204, JIS A 6205, JSCE-D 101, and JSCE-D 104, respectively.

(3) As for admixtures other than the above, their quality shall be confirmed, and the method of use with ground slag and the resulting concrete properties shall be confirmed by testing.

[Commentary]

Regarding (1): When using fly ash, an expansive additive, or silica fume in combination with ground slag, they should conform to JIS A 6201 (Fly ash for concrete), JIS A 6202 (Expansive additive for concrete), and JSCE-D 106 (Standard specification for silica fume for use in concrete-Draft), respectively.

Regarding (2): When using chemical admixtures, a corrosion inhibitor, superplasticizer, or admixture for antiwashout underwater concrete, they should conform to JIS A 6204 (Chemical admixtures for concrete), JIS A 6205 (Corrosion inhibitor for reinforcing steel in concrete), JSCE-D 101 (Standard specification for superplasticizers for concrete), and JSCE-D 104 (Standard specification for admixtures for antiwashout underwater concrete-Draft), respectively. The use of chemical admixtures for concrete, such as an air-entraining agent, water-reducing agent, air-entraining and water-reducing agent, air-entraining and high-range water-reducing agent, and superplasticizer is recommended as in the case of concrete containing no ground slag.

It should be noted that the dosage of an air-entraining agent (or the air-entraining component in an air-entraining and water-reducing agent) to obtain the required air entrainment tends to increase as the fineness and/or replacement ratio of ground slag increases. The effect of a water-reducing agent may be assumed to be the same as or stronger than on ordinary concrete. However, if a water-reducing agent of the type that significantly retards setting and hardening is to be used, its type and dosage as well as the gypsum content in ground slag should be selected by testing.

CHAPTER 4 MIX PROPORTIONS

4.1 General

Mix proportions of concrete containing ground slag as a mineral admixture shall be established so as to minimize the unit water content within the range of providing the required strength, durability, watertightness, resistance to cracking, steel-protective capability, as well as adequate workability.

[Commentary]

Mix proportions of concrete containing ground slag are basically the same as those of concrete containing no ground slag, and to establish them so as to minimize the unit water content is a basic premise of proportioning. In addition, it is important to select the mix proportions so that the purpose of using ground slag can be sufficiently fulfilled.

4.2 Type and replacement ratio of ground slag

(1) The type and replacement ratio of ground slag shall be adequately selected so that the purpose of using ground slag can be sufficiently fulfilled.

(2) The ground slag replacement ratio shall, as a rule, be appropriately selected within a range of ground slag-binder ratio by mass of 30% to 70%.

[Commentary]

When using ground slag for concrete, one type should be selected from among ground slags 4000, 6000, and 8000, and an appropriate replacement ratio should be selected, as a rule, within the range of 30% to 70% in terms of the percentage of the mass of ground slag in the total mass of the binders, so that the purpose of using ground slag is fulfilled. The selection should be made referring to Table C 2.2.2 in consideration of the points stated in the commentary of Sections 2.1, 2.2 and 3.2.

4.3 Water-binder ratio

The lowest water-binder ratio shall be selected from the range determined in consideration of the required strength, durability, watertightness, crack resistance, and steel-protective capability of concrete.

(1) The water-binder ratio shall not exceed 65%, as a rule.

(2) When establishing the water-binder ratio {W/(C+BF)} based on compressive strength of concrete, the value shall be selected as follows:

(a) The relationship between compressive strength and the water-binder ratio shall, as a rule, be determined by testing. The standard test age shall be 28 days.

(b) The water-binder ratio to be used for proportioning shall be the inverse number of the binder-water ratio, (C+BF)/W, corresponding to the proportioning strength, f'_{cr}, on the relationship line between the binder-water ratio and the compressive strength, f'_c, at the specified age. This proportioning strength shall be obtained by multiplying the design strength, f'_{ck}, by an appropriate factor. This factor shall be determined according to the variation coefficient of compressive strength of concrete expected at each construction site, and normally be the value obtained from the curve shown in Fig. 4.3.1.

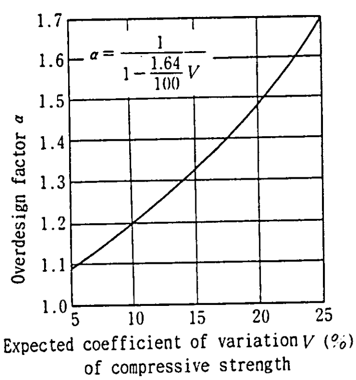


Fig. 4.3.1 Overdesign factor for general use

(3) In the case of establishing the water-binder ratio based on the resistance of concrete to freezing and thawing, the water-binder ratio shall not exceed the values given in Table 4.3.1.

Table 4.3.1 Maximum water-binder ratio of air-entrained concrete containing ground slag when the freeze-thaw resistance is the determining factor

Exposure class \ Weather conditions / Cross section	Severe weathering or frequent cycles of freezing and thawing		Moderate weathering, rarely freezing	
	Thin[2]	Normal	Thin[2]	Normal
(1) Portions constantly or frequently saturated with water[1]	55	60	55	65
(2) Portions under normal exposure conditions and other than (1)	60	65	60	65

1) Structures close to water surfaces and saturated with water, e.g., waterways, water tanks, bridge abutments, bridge piers, retaining walls and tunnel lining, as well as those away from water surfaces but saturated with melted snow, water flow, or water splash, e.g., bridge girders and slabs.

2) Portions where the cross sectional thickness is 20 cm or less.

(4) In the case of concrete to be used for marine structures, the standard maximum water-binder ratio determined from the durability shall be the values given in Table 4.3.2.

Table 4.3.2 Maximum water-binder ratio of air-entrained marine concrete containing ground slag when the durability is the determining factor

Exposure class \ Construction conditions	General in-situ concreting	Precast products or where the quality equivalent to precast products is assured by the selection of materials and quality of concreting
(a) In marine air	45	50
(b) Splash zones	45	45
(c) Submerged zones	50	50

Note: Where the durablity is confirmed by field experience and study results, the values of Table 4.3.2 plus 5 to 10 may be adopted as the water binder ratio based on durability.

(5) In the case of establishing the water-binder ratio based on durability against chemical attacks on concrete, the following method shall be employed.

(a) For concrete in contact with soil or water containing sulfate equivalent to SO_4 of 0.2% or more, the water-binder ratio shall not exceed the values given in Table 4.3.2 (c).

(b) For concrete where a deicing agent is expected to be used, the water-binder ratio shall not exceed the values given in Table 4.3.2 (b).

(6) In the case of establishing the water-binder ratio based on watertightness, the water-binder ratio shall not exceed 55%.

[Commentary]

Regarding (1): In the case of establishing the water-binder ratio in consideration of the required strength, durability, watertightness, crack resistance, and steel-protective capability, the minimum water-binder ratio rarely exceeds 65% even when ground slag is used. In addition, it has been empirically known that concrete for structural members with a water-binder ratio of more than 65% tends to pose quality problems. A water-binder ratio of not more than 65%, as a rule, was therefore specified in the present Recommendations.

Regarding (2) (a): Similarly to the case of concrete containing no ground slag, the compressive strength of concrete containing a fixed type and replacement ratio of ground slag has a linear relationship with the binder-water ratio. Accordingly, the water-binder ratio is required, as a rule, to be determined from the relationship between the compressive strength and the binder-water ratio of concrete containing ground slag of the selected type and replacement ratio.

Regarding (2) (b): The variation coefficient of compressive strength of concrete containing ground slag may be assumed to be nearly the same as that of concrete containing no ground slag.

Regarding (3), (4), (5), and (6): A number of experiments and construction records have ascertained that concrete containing ground slag has the same or a higher freeze-thaw resistance, durability against sea water, durability against chemical actions, and watertightness than concrete containing no ground slag, provided properly cured with an equivalent water-binder ratio. This is because concrete containing ground slag forms dense microstructure and because ground slag in place of cement reduces calcium hydroxide. Accordingly, where the water-binder ratio is established on the basis of durability and watertightness, simply applying the values of water-cement ratio of concrete containing no ground slag to the water-binder ratio of concrete containing ground slag is expected to lead to sufficiently durable and watertight concrete. The water-binder ratio is therefore required to be established in line with the values specified in the Standard Specification [Construction].

It should be noted that ground slag to be used for concrete in contact with soil or water containing sulfate equivalent to SO_4 of 0.2% or more should preferably contain gypsum equivalent to SO_3 of not less than 2%.

4.4 Unit water content

(1) Unit water content shall be established by testing so as to be the lowest within the workable range.

(2) When using an air-entraining and high-range water-reducing agent, the unit water content shall, as a rule, be not more than 175 kg/m^3.

[Commentary]

Regarding (1): Approximate values of standard unit water content to attain the required slump are presented in Table C 4.4.1. As given in the figure, the unit water content for concrete containing ground slag is lower than concrete containing no ground slag on the same slump level by 2% to 5% depending on the type and replacement ratio of ground slag. When the temperature of freshly mixed concrete is 10℃ higher or lower, the unit water content required to obtain the same slump increases or decreases by 2% to 3%.

Regarding (2): Concrete containing an air-entraining and high-range water-reducing agent must conform to JSCE Recommendations for Concrete Containing an Air-entraining and High-range Water-reducing Agent (Draft). This unit water content requirement for concrete containing ground slag is the same as that for concrete containing no ground slag.

Table C 4.4.1 Approximate values of unit coarse aggregate volume, sand-aggregate ratio, and unit water content of concrete

Maximum aggregate size (mm)	Unit coarse aggregate volume (%)	Air-entrained concrete				
		Air content (%)	With air-entraining agent		With air-entraining and water-reducing agent	
			Sand-aggregate ratio s/a(%)	Unit water content W(kg)	Sand-aggregate ratio s/a(%)	Unit water content W(kg)
15	59	7.0	46	175	47	165
20	63	6.0	43	170	44	160
25	68	5.0	41	165	42	155
40	73	4.5	38	160	39	150

(1) These values apply to concrete containing ground slag 4000 at a replacement ratio of 50%, sand with a normal grading (FM: 2.80) as fine aggregate, and crushed stone as coarse aggregate, and with a water-binder ratio of 0.55 and a slump of about 8 cm.

(2) Where the materials or qualities of concrete are different from those stated in (1) above, the values shall be corrected as given below:

Class			Correction of s/a (%)	Correction of W (kg)
Per 10% point increase (decrease) in ground slag replacement ratio	Type	Ground slag 4000	No correction	Reduce (increase) by 1.5 kg
		Ground slag 6000	No correction	Reduce (increase) by 1.5 kg
		Ground slag 8000	Reduce (increase) by 0.5	Reduce (increase) by 1.0 kg
Per 0.1 increase (decrease) in fineness modulus of sand			Increase (reduce) by 0.5	No correction
Per 1 cm increase (decrease) in slump			No correction	Increase (reduce) by 1.2% points
Per 1% point increase (decrease) in air content			Reduce (increase) by 0.5 to 1	Reduce (increase) by 3% points
Per 0.05 increase (decrease) in water-binder ratio			Increase (reduce) by 1	No correction
Per 1% point increase (decrease) in s/a			—	Increase (reduce) by 1.5 kg
Where river sand is used			Reduce by 3 to 5	Reduce by 9 to 15 kg
Where gravel is used			Increase by 2 to 3	Increase by 6 to 9 kg

Where the correction is made to the unit coarse aggregate volume, reduce (or increase) it by 1 percentage point per 0.1 increase (or decrease) in the fineness modulus of sand.

4.5 Binder content

(1) Binder content shall, as a rule, be determined from the unit water content and water-binder ratio.

(2) When a lower or upper limit is specified for the binder content, the limit shall be observed.

[Commentary]

Regarding (2): When using ground slag as well, significantly high binder content is required to obtain concrete with the required strength, durability, watertightness, etc. Also, a lower or upper limit is specified for the binder content of concrete containing air-entraining and high-range water-reducing agent, marine concrete, underwater concrete, mass concrete, etc. The allowable range of binder content must therefore be confirmed referring to relevant parts of the present Recommendations, other relevant recommendations, and the Standard Specification [Construction].

4.6 Sand-aggregate ratio

The sand-aggregate ratio shall be established by testing so that the unit water content can be minimized while adequate workability is obtained.

[Commentary]

Due to the large specific surface of ground slag and an increased volume of paste resulting from its specific gravity smaller than that of cement, the sand-aggregate ratio of concrete containing ground slag can be lower than that of concrete containing no ground slag, according to its type and replacement ratio. The sand-aggregate ratio and unit coarse aggregate volume given in Table C 4.4.1 were determined by correcting the values given in Table C 4.8.1 of the Standard Specification [Construction] in consideration of this point.

4.7 Dosage of admixtures

(1) The dosage of an air-entraining agent, water-reducing agent, air-entraining and water-reducing agent, and air-entraining and high-range water-reducing agent shall be established by testing so as to provide the required consistency, water-reducing effect, and air content.

(2) The dosage of admixtures other than those mentioned in (1) above shall be established on the basis of test results and field experience so as to provide the required effects.

[Commentary]

Regarding (1): The dosage of an air-entraining agent (the air-entraining component in the case of an air-entraining and water-reducing agent and air-training and high-range water-reducing agent) to obtain the required air content tends to be higher than that of concrete containing no ground slag. This tendency becomes stronger as the ground slag replacement ratio increases and as its specific surface increases.

The use of ground slag may be considered to scarcely affect the degrees of time-dependent changes in slump and air content.

4.8 Form for expressing mix proportions

(1) Mix proportions of concrete shall be generally indicated in the form shown in Table 4.8.1.

(2) In the specified mixes, fine aggregate is defined as entirely passing a 5 mm sieve, and coarse aggregate, entirely retained on a 5 mm sieve. Both aggregates shall be expressed in terms of their respective saturated surface-dry conditions.

(3) When modifying the specified mix proportions into field mix proportions, the following shall be taken into account: water absorption of aggregate, percentage of fine aggregate retained on a 5 mm sieve, percentage of coarse aggregate passing a 5 mm sieve, and the quantity of water used to dilute chemical admixtures.

Table 4.8.1 Form for expressing mix proportions

Max. aggregate size	Slump	Air content	Water-binder ratio	Replacement ratio	Sand-aggregate ratio	Unit content (kg/m³)							
						Water	Binder		Fine aggregate	Coarse aggregate G		Admixtures	
			$\frac{W}{C+BF}$	$\frac{BF}{C+BF}$	s/a		Cement	Ground slag		mm ~ mm	mm ~ mm	Mineral admixture	Chemical admixture
(mm)	(cm)	(%)	(%)	(%)	(%)	W	C	BF	S				

Note: Express the chemical admixture dosage by ml/m3 undiluted and undissolved.

CHAPTER 5 PRODUCTION AND PLACING OF CONCRETE

5.1 General

(1) When producing concrete containing ground slag as a mineral admixture, the materials shall be stored, weighed, and mixed using equipment having the required performance, so that concrete with the required qualities can be produced.

(2) Adequate plans shall be formulated prior to transporting and placing concrete containing ground slag.

[Commentary]

Regarding (2): When formulating a transportation and placing plan for concrete containing ground slag, it is important to take account of the fact that a high replacement ratio retards setting and that low concrete placing temperature adversely affects both early and long-term strength gains.

5.2 Storage facility for ground slag

The structure of the storage facility for ground slag shall be such that prevents alteration of quality and inclusion of foreign substances during storage.

[Commentary]

Moisture in air can cause caking and deterioration of ground slag. For this reason, ground slag should be protected from moisture, and venting should also be avoided during storage. Requirements for ground slag storage facility are basically the same as those for cement. Its capacity should be not less than three times the average daily need.

Different brands of the same type of ground slag cannot be treated as having the same quality, as they may have different fineness or gypsum content. Therefore the storage facility must be capable of accommodating different brands separately.

5.3 Batching of ground slag

(1) The batching equipment for ground slag shall, as a rule, be dedicated to this purpose, and shall be capable of weighing the quantity within the specified allowances for batching errors.

(2) Ground slag shall be weighed by mass for each batch of concrete.

(3) Batching errors for ground slag shall not be greater than 1% per batch.

[Commentary]

Regarding (1): Ground slag forms a part of the binders and is a material by which the qualities of concrete are sensitively affected. An excessive batching error could cause not only failure to provide the required qualities of concrete, but also failure to fulfill the purpose of use of the entire concrete structure made using this concrete. Accordingly, dedicated batching equipment is required to be used, as a rule.

Regarding (3): Ground slag is treated basically as a binder similar to cement, as it is latently hydraulic and used normally at a proportion of 30% to 70% of the binders. Therefore the same allowances for batching error as cement are specified for ground slag.

5.4 Mixing

(1) Concrete materials shall be thoroughly mixed until the concrete becomes uniform.

(2) The order of charging materials into the mixer shall be appropriately established in advance.

(3) The mixing time shall, as a rule, be established by testing.

[Commentary]

Regarding (2): In order to disperse ground slag uniformly in concrete, it is generally advisable to charge ground slag into the mixer simultaneously with cement or immediately following cement.

Regarding (3): Overseas and domestic mixing tests in which cement and ground slag are simultaneously charged into the mixer revealed that ground slag has good dispersibility when mixed, and the resulting concrete has nearly the same uniformity as ordinary portland cement and portland blast-furnace cement. For this reason, when no mixing time test is conducted, a minimum mixing time of one half minutes and one minute may be adopted as a standard for tilting type mixers and forced mixing type batch mixers, respectively, as is the case of ordinary concrete, provided that the plant is furnished with well-maintained equipment.

5.5 Transportation and placing

(1) Concrete shall be transported quickly, placed immediately, and consolidated fully. The time from the start of mixing to the completion of the placing shall, as a rule, not exceed one and a half hours when the outdoor temperature is above 25℃, and two hours when it is 25℃ or below.

(2) The concrete placing temperature shall, as a rule, be not lower than 10℃.

[Commentary]

Regarding (1): Concrete containing ground slag may be transported and placed in the same manner as concrete containing no ground slag.

Regarding (2): Strength development of concrete containing ground slag is strongly affected by the temperature of concrete when hardening. If the concrete temperature at placing is low and if it is not maintained at 10℃ or higher during curing, the required strength may not be attained not only at early ages but also at later specified ages. In the case of mass concrete, the placing temperature requirement may be reduced to not lower than 7℃, provided that the concrete is adequately cured, since temperature rise due to hydration heat from hardening concrete is anticipated.

CHAPTER 6 CURING

6.1 General

After placement, concrete containing ground slag shall be cured by being kept in the necessary temperature and humidity conditions required for hardening and protected from the effects of deleterious environmental conditions.

[Commentary]

The qualities of concrete containing ground slag are strongly affected by the quality of moist curing, particularly at early ages, when compared with concrete containing no ground slag. Sufficient care should therefore be exercised in regard to curing.

6.2 Moist curing

(1) When curing concrete, moisture loss due to exposure to direct sunlight and wind shall be prevented. Exposed surfaces of concrete shall also be maintained wet throughout the curing period.

(2) When concrete has hardened sufficiently to allow working without damaging the surfaces, exposed surfaces shall be maintained wet by being covered with a curing mat, wet cloth, or other materials, or by spraying or ponding for the rest of the curing period.

6.3 Period of moist curing

The curing period of concrete containing ground slag shall, as a rule, be established by testing.

[Commentary]

Initial curing is particularly important for concrete containing ground slag, and the period during which the concrete is maintained wet should be longer than that for concrete made using ordinary portland cement without ground slag.

Table C 6.3.1 gives the standard curing periods for concrete containing ground slag. These values are based on the curing periods at which concretes containing ground slag in place of about 50% of cement with a water-cement ratio of 45% to 55% attain a compressive strength ratio of 50% to their 28-day strength. The air temperature and curing temperature conditions are equalized. The moist curing period required for concrete containing ground slag with a higher fineness can be estimated shorter, as a higher fineness tends to lead to a larger early strength gain.

Table C 6.3.1 Standard minimum period of moist curing
(Where the water-binder ratio combined with ordinary portland cement is around 50%)

Replacement ratio(%)	30~40	50			55~70
Daily mean temperature (℃) / Type of ground slag	Ground slag 4000	Ground slag 4000	Ground slag 6000	Ground slag 8000	Ground slag 4000
17	6 days	7 days	7 days	6 days	8 days
10	9 days	10 days	9 days	8 days	11 days
5	12 days	13 days	12 days	10 days	14 days

6.4 Curing temperature

During the curing period, the temperature of concrete surfaces shall, as a rule, be maintained at not lower than 10℃.

[Commentary]

Low air temperature can cause delayed strength development and early frost damage of concrete containing ground slag, and this is not limited to the case of cold weather concreting. For this reason, it is desirable that the surfaces of concrete be maintained at 10℃ or above during the curing period by heating or insulation with care to avoid their rapid drying. Care should be exercised particularly regarding thin members. In the case of mass concrete as well, it is desirable that the surfaces of concrete be maintained at 7℃ or above.

The use of ground slag 6000 or ground slag 8000 mitigates the losses in strength gains caused by low curing temperature to a certain extent. However, it is desirable that heat-insulated curing be done in this case as well, since the strength gains are small up to about 7 days.

6.5 Accelerated curing

For accelerated curing, such as steam curing and heat curing, the heating rate, cooling rate, curing temperature, and curing period shall be established, so as to avoid adverse effects on the concrete.

[Commentary]

When using ground slag, particular care should be exercised, such as to delay the start of accelerated curing and extend the subsequent wet curing period.

CHAPTER 7 READY-MIXED CONCRETE

7.1 General

When ordering and using concrete containing ground slag as ready-mixed concrete, the concrete shall conform not only to these Recommendations but also, as a rule, to JIS A 5308.

[Commentary]

JIS A 5308 (Ready-mixed concrete) specifies a number of requirements regarding materials, types, designations, quality, proportioning, production, quality control, test methods, and inspection methods. Ready-mixed concrete containing ground slag generally shall meet these requirements. However, the requirements of JIS A 5308 provide fundamental rules applicable to ready-mixed concrete in general. For concretes requiring special care, it is desirable that recommendations and guidelines for specific types of concrete give detailed instructions. Also, JIS requirements may deviate from the requirements of the present and other JSCE Recommendations, as in the case of air content.

In consideration of these points, when ordering and using concrete containing ground slag covered by the present Recommendations as ready-mixed concrete, the concrete is required to conform to JIS A 5308 as a rule, and also required to satisfy the requirements of the present Recommendations.

7.2 Selection of concrete plants

(1) The suppliers' plant of ready-mixed concrete shall be selected from among JIS-accredited plants operated or controlled by personnel who are authorized by JCI as Chief Concrete Engineer or Concrete Engineer, or engineers who have knowledge and experience comparable or superior to them.

(2) When selecting a plant, the following matters shall be taken into account: the storage facility for ground slag, batching equipment, batching recorders, transportation time to the site, unloading time, concrete production capacity, number of transportation vehicles, and state of quality control.

[Commentary]

Regarding (2): The plant to be selected should be furnished with equipment to store ground slag under the same conditions as those for cement and equipment to batch it with the same accuracy as cement. It should also be capable of carrying out adequate quality control and shipment control. At the same time, it is desirable to select a plant equipped with a batching recorder that prints out the measurements so that the quantity of ground slag used can be confirmed.

7.3 Specification of qualities

When ordering a ready-mixed concrete containing ground slag, the purchaser shall specify the type of ready-mixed concrete, as well as type of cement, and type and replacement ratio of ground slag. The purchaser shall further specify the following items, where required, by consulting with the manufacturer:

(a) Type of aggregate
(b) Age of concrete to assure the nominal strength
(c) Air content
(d) Maximum or minimum temperature of concrete
(e) Other requirements

[Commentary]

In the case of concrete containing ground slag, a significant strength gain can normally be anticipated beyond 28 days. Accordingly, it may be economical to specify a later age to assure the nominal strength by consulting with the manufacturer for certain uses and ground slag replacement ratios.

Water-cement ratio and unit binder content are included in (e) other requirements.

Portland blast-furnace slag cement on the market contains ground slag comparable to ground slag 4000 as an additive, which is uniformly preblended with portland cement at cement plants. It is widely used and has numerous application records. For this reason, it may be convenient to consider first the use of portland blast-furnace slag cement where it can also ensure the required qualities.

7.4 Acceptance of supplied concrete

(1) Acceptance of supplied ready-mixed concrete shall be in accordance with the provisions of "Acceptance of supplied concrete" in the chapter of "Ready-mixed concrete" of the Standard Specification [Construction].

(2) When the ground slag replacement ratio in fresh concrete is to be tested, the tests shall,

as a rule, be conducted in accordance with JSCE-D 501.

[Commentary]

Regarding (2): JSCE has explored a simple and accurate method of testing the ground slag replacement ratio in fresh concrete, and established JSCE-D 501 (Test Method for Combined Ratio and Replacement Ratio of Ground Slag). Accordingly, this method is required to be used when ground slag replacement ratio and / or combined ratio in fresh concrete is to be tested.

However, the ground slag replacement ratio may be confirmed by the batching record for the purpose of routine quality control and inspection.

CHAPTER 8 QUALITY CONTROL AND INSPECTION

8.1 General

(1) Quality control and inspection of the general operation of construction, including concrete materials and construction methods, shall be carried out in order to economically construct concrete structures with the required qualities.

(2) Inspection is passed, if the judgment criteria are met by the results of tests to confirm that the concrete structure has the required quality.

[Commentary]

Regarding (2): Inspection should be carried out by judging if the results of required tests conform to the judgment criteria specified in the Standard Specification [Construction], design documents, statement of construction methods, etc. In some cases the results of quality control tests are used, instead of conducting separate tests for inspection.

8.2 Tests

(1) Tests shall be conducted, as a rule, in accordance to the methods provided in JIS, JSCE specifications, and other specifications.

(2) Tests must be conducted at the specified time and frequency.

[Commentary]

Regarding (2): The time and frequency of tests should be determined in consideration of the type, scale, and period of construction. Required tests should be conducted on materials, concrete production, and concrete qualities at the specified time and frequency, for instance, once before the start of construction, once every day or every month during the construction period, etc.

8.3 Quality control and inspection of materials

(1) Quality control and inspection of ground slag shall be conducted for the items specified in JIS A 6206.

(2) Quality control and inspection of cement, mixing water, aggregate, and other admixtures shall be conducted in accordance with the Standard Specification [Construction].

(3) Should the quality of any material be judged inadequate by the inspection, appropriate measures, such as to improve or change the material, shall be taken. In case concrete containing the material should be placed in the structure, an assessment shall be made as to whether or not the structure can fulfill the required purpose.

[Commentary]

Regarding (1): Quality control and inspection of ground slag should be carried out for all items specified in JIS A 6206 (Ground granulated blast-furnace slag for use in concrete), namely specific gravity, specific surface, activity index, flow value ratio, magnesium oxide content, sulfur trioxide content, ignition loss, and chloride ion content, by ascertaining that they satisfy the requirements.

The activity index to assess the strength-developing property is required to be tested with a ground slag replacement ratio of 50% and a water-binder ratio of 50%. However, a considerably different ratio may be specified for certain uses. In such a case, it is desirable that the strength be directly assessed under the actual conditions. The specific surface greatly affects the strength development and properties of fresh concrete. As the measurement of specific surface is relatively easy, it is advisable to control the specific surface at an increased frequency.

The tests for these items should be conducted in accordance with JIS A 6206, but the qualities of ground slag may generally be confirmed by the test reports received from the suppliers' plant.

8.4 Quality control and inspection of concrete production

(1) Quality control and inspection of production of concrete containing ground slag shall, as a rule, be conducted in accordance with the Standard Specification [Construction].

(2) Should concrete production be judged inadequate by the inspection, appropriate measures, such as to improve the equipment and production process, shall be taken. In case the produced concrete should be placed in the structure, an assessment shall be made as to whether or not the structure can fulfill the required purpose.

[Commentary]

Regarding (1): It is desirable that dedicated facility be used for the storage of ground slag to avoid inclusion of other binders. Also, when ground slag is to be conveyed to the batching plant with the same equipment used for cement, it must be confirmed that no material previously conveyed remains in the conveying equipment.

The tolerances for batching error of the batching equipment for ground slag should be within 1%, the same as that for cement.

In the case of concrete containing ground slag, a small difference in the quantity of materials, particularly that of ground slag, can lead to a large difference in the properties of concrete. It is therefore important to carry out quality control of mix proportions and batching of each material with special care.

It is advisable to confirm the uniformity of ground slag in concrete in accordance with JSCE-D 501 (Test Method for Combined Ratio and Replacement Ratio of Ground Granulated Blast-Furnace Slag).

8.5 Quality control and inspection of concrete

(1) Quality control and inspection of concrete containing ground slag as a mineral admixture shall, as a rule, be carried out in accordance with the Standard Specification [Construction].

(2) Tests for ground slag replacement ratio shall conform to JSCE-D 501.

(3) Where quality control of concrete is based on compressive strength, the compressive strength at an early age shall be used. In this case, the specimens shall be taken so that they represent the concrete in the structure.

(4) Inspection of concrete based on compressive strength shall be carried out by testing compressive strength at an age that the proportioning was based on.

(5) Should the quality of concrete be judged inadequate, appropriate measures shall be taken, such as to inspect the materials, correct the mix proportions, inspect the production equipment, and improve the work procedure. In addition, an assessment shall be made as to whether or not the concrete placed in the structure can fulfill the required purpose.

[Commentary]

Regarding (2): In the case where the ground slag replacement ratio is specified for a specific purpose, such as to increase the durability and reduce the heat of hydration, quality control and inspection should be made to confirm that the specified replacement ratio is contained. In this case, the test should conform to JSCE-D 501 (Test Method for Combined Ratio and Replacement Ratio of Ground Granulated Blast-Furnace Slag).

8.6 Quality control of transportation, placing, and curing

(1) Quality control of transportation, placing, and curing of concrete containing ground slag as a mineral admixture shall be carried out in accordance with the Standard Specification [Construction].

(2) Should transportation, placing, or curing be judged inadequate, appropriate measures shall be taken so that the required purpose can be fulfilled.

(3) When determining the adequacy of curing, time to remove formwork, and time to apply prestress, or when assessing safety of early loading, strength tests shall be conducted on specimens cured under the conditions simulating those of concrete on site.

[Commentary]

Regarding (1): Method and period of curing are critical items to develop fully the properties of concrete containing ground slag. These items should therefore be adequately established in consideration of the type and replacement ratio of ground slag and weather conditions, and control should be carried out with care.

CHAPTER 9 MASS CONCRETE

9.1 Scope

This chapter provides the general requirements for matters particularly necessary when ground slag is used as a mineral admixture for construction of mass concrete structures, as well as general requirements for controlling temperature cracking of mass concrete structures containing ground slag as a mineral admixture.

[Commentary]

Concrete containing ground slag generally tends to have low hydration-induced exotherm rate and low heat generation, and therefore is suitable for mass concrete.

9.2 General

When using ground slag for mass concrete as a mineral admixture, a construction plan shall be formulated after thoroughly examining the thermal stress and temperature cracking due to hydration heat of cement so that the concrete structure can attain the required qualities and function. The practice of mass concreting shall conform to the construction plan.

[Commentary]

As concrete containing an adequate amount of ground slag of adequate quality reduces the exotherm rate, it can be utilized as a measure for temperature crack control by means of selection of materials and mix proportions. However, certain activity index or replacement ratios of ground slag can accelerate the heat generation, increasing the temperature rise. It is therefore important to maintain the concrete placing temperature as low as practicable.

9.3 Materials and mix proportions

Materials and mix proportions of mass concrete containing ground slag shall be selected so as to minimize the temperature rise of concrete within the range of providing the required performance.

[Commentary]

When using ground slag for mass concrete, the fineness should be as low as possible in the range of satisfying the requirements, and the replacement ratio should be in the range of 50% to 70%.

It is advisable to consider the use of a retarding type chemical admixture to reduce the exotherm rate and prevent cold joints.

9.4 Assessment of temperature cracking

9.4.1 General

The possibility of temperature cracking in mass concrete shall be assessed by either of the following methods:

(1) Assessment based on experience
(2) Assessment based on the temperature crack index

9.4.2 Thermal properties of concrete

(1) The adiabatic temperature rise characteristics of concrete shall, as a rule, be determined by testing.

(2) The values representing thermal properties to be used in temperature analysis of concrete shall be adequately determined on the basis of such factors as the materials, mix proportions, and placing temperature.

[Commentary]

Regarding (1): The adiabatic temperature rise of concrete is a fundamental constant for the analysis of temperature changes within concrete after the placement, and is generally expressed by Eq. C 9.4.1.

$$Q(t) = Q_\infty \left\{1 - \exp(-\gamma t)\right\} \quad \text{(Eq. C 9.4.1)}$$

where Q_∞ = ultimate adiabatic temperature rise (℃) to be determined by experiment
γ = constant for temperature rise rate to be determined by experiment
t = age (days)
Q(t) = adiabatic temperature rise at t days (℃)

The ultimate temperature rise (Q_∞) of concrete made using ordinary portland cement partially replaced with ground slag is about 10% larger than concrete containing no ground slag when the replacement ratio is 60% or lower. However, the temperature rise has been proven to decrease significantly with a replacement ratio of more than 65%. The constant for temperature rise rate r of concrete containing ground slag with a specific surface of 3000 to 6000 cm^2/g is smaller than 2/3 of that of concrete made using ordinary portland cement without ground slag. A reduction in the concrete temperature rise by radiation can therefore be anticipated.

9.4.3 Mechanical characteristic values of concrete

(1) The tensile strength of concrete containing ground slag to be used shall be an adequate value in consideration of such factors as the fineness and replacement ratio of ground slag, type of cement, water-binder ratio, age, and variability of strength.

(2) Effective Young's modulus to calculate the thermal stress shall be adequately determined in consideration of the effect of age.

[Commentary]

Regarding (2): Since the magnitude of thermal stress is determined by the temperature gradient within the concrete and the ratio of rigidity of the restraining body to that of the restrained body, it is necessary to evaluate effective Young's modulus of the hardening restrained body concrete. For the thermal stress calculation, the present Recommendations use average effective Young's modulus of the cross sections of the restrained body concrete taking account of the rigidity losses due to creep and relaxation.

CHAPTER 10 COLD WEATHER CONCRETING

10.1 Scope

This chapter provides the general requirements for matters particularly necessary when ground slag is used for cold weather concreting as a mineral admixture.

When the daily mean temperature is expected to drop to below 4℃, concreting shall be conducted as cold weather concreting.

10.2 General

When using ground slag for cold weather concreting, adequate care shall be exercised particularly regarding materials and proportioning, transportation and placing, and curing so that freezing of concrete can be prevented and concrete placed in cold weather can develop the required qualities.

[Commentary]

Setting and hardening of concrete containing ground slag are significantly delayed at a low temperature when compared with concrete containing no ground slag, leading to low initial strength and vulnerability to frost damage. In order to prevent this, measures should be taken, such as to select adequate materials and mix proportions, control concrete temperature during transportation and placing, and carry out temperature-controlled curing, for instance, insulation curing.

10.3 Materials and mix proportions

(1) The type and replacement ratio of ground slag shall be adequately selected in consideration of their effects.
(2) An adequate air-entraining agent, air-entraining and water-reducing agent, or air-entraining and high-range water-reducing agent shall be used, which shall conform to JIS A 6204.

[Commentary]

Regarding (1): When using ground slag for cold weather concreting, it is more advantageous for streamlined construction to select a type with a high fineness. If the percentage of gypsum addition (SO_3 equivalent) is around 3% or less, a higher gypsum percentage is reported to lead to a higher initial strength while producing no appreciable adverse effects on the long-term strength. It is therefore desirable to pay attention to the gypsum percentage as well.

Regarding (2): The use of an air-entrained concrete with an adequate air content for cold weather concreting is standard practice. This also applies to concrete containing ground slag.

10.4 Transportation and placing

The concrete placing temperature shall be established in the range of 7 to 25℃ in consideration of the minimum cross-sectional size of the structure and weather conditions.

[Commentary]

It is advisable to establish the concrete placing temperature in the range of 7 to 25℃ and so as not to differ widely from the curing temperature. Table C 10.4.1 gives the standard values of concrete placing temperature recommended for general cold weather concreting.

Table C 10.4.1 Recommended concrete placing temperature ranges

Member thickness / Temperature range(℃)	Thin	Normal	Thick
Lower limit	13	10	7
Upper limit	15	20	20

10.5 Curing

The curing temperature of concrete subjected to severe weather conditions shall, as a rule, be maintained at not less than the lower limit of the range of concrete placing temperature specified when formulating the construction plan until the compressive strength given in Table 10.5.1 is attained. After attaining this compressive strength, the concrete shall be maintained at not less than the specified temperature for at least the following three days and at not less than 0℃ for two days thereafter.

Table 10.5.1 Standard compressive strength required at the end of curing where concrete is exposed to severe weathering (N/mm²)

Cross section / Exposure class	Thin	Normal	Thick
(1) Portions constantly or frequently saturated with water	15	12	10
(2) Portions under normal exposure conditions and other than (1)	5	5	5

[Commentary]

The curing period required to obtain the strength given in Table 10.5.1 depends on such factors as the activity index and replacement ratio of ground slag, binder content, and curing temperature. Accordingly, this should be determined, as a rule, by the compressive strength of concrete specimens cured under the same conditions as the structure. Table C 10.5.1 gives the standard curing periods of concrete containing ground slag 4000 in place of 40% to 55% of ordinary portland cement with a water-binder ratio of 55%.

Table C 10.5.1 Standard curing period when the curing temperature is 10℃ for a concrete of a normal thickness containing ground slag 4000 in place of 40 to 55% of ordinary portland cement with a water-binder ratio of 55%

Exposure class	Curing period
(1) Portions constantly or frequently saturated with water	9 days
(2) Portions under normal exposure conditions and other than (1)	4 days

CHAPTER 11 HOT WEATHER CONCRETING

11.1 Scope

This chapter provides the general requirements for matters particularly necessary when using concrete containing ground slag as a mineral admixture for hot weather concreting.

When the construction is scheduled for the season in which the daily mean temperature exceeds 25℃, preparations shall be made for hot weather concreting.

11.2 General

When using concrete containing ground slag for hot weather concreting, adequate measures shall be taken particularly for materials and proportioning, transportation and placing, and curing, to prevent deterioration of concrete quality due to high temperature.

[Commentary]

Ground slag generally retards the rates of hydration and setting of the binders as a whole of concrete when compared with the case of concrete made using ordinary portland cement with no ground slag. Concrete containing ground slag therefore reduces the risk caused by rapid hydration and setting and allows more time for transportation and placing. From this aspect, it is advantageous for hot weather concreting. In hot weather, however, concrete is subjected to rapid drying, and the degree of drying increases as the setting is retarded. Care must be exercised in regard to this point when using concrete containing ground slag.

11.3 Materials and mix proportions

(1) The type and replacement ratio of ground slag shall be adequately selected in consideration of their effects.

(2) When using an air-entraining agent, water-reducing agent, air-entraining and water-reducing agent, or air-entraining and high-range water-reducing agent as a chemical admixture, those conforming to JIS A 6204 shall, as a rule, be used. The water-reducing agent and air-entraining and water-reducing agent shall be of the retarding type specified in JIS A 6204.

(3) When using a superplasticizer, one conforming to the retarding type specified in JSCE-D 101 shall be used.

[Commentary]

Regarding (1): The slump loss over time of concrete containing ground slag is small in hot weather when compared with concrete containing no ground slag. It is therefore advantageous, allowing a long transportation time and causing few cold joints. In order to make the most of this advantage, it is desirable that the ground slag replacement be increased to a highest practicable ratio, at 50% to 70%.

11.4 Transportation and placing

Mixed concrete shall be transported and placed by means of adequate equipment and procedures so as to minimize drying and heating.

11.5 Curing

Beginning immediately after placement, concrete shall be cured so as to protect its surfaces from drying.

[Commentary]

Excessive drying of concrete containing ground slag at early ages tends to adversely affect later strength development. Sufficient moist curing is therefore necessary.

CHAPTER 12 MARINE CONCRETE

12.1 Scope

This chapter provides the general requirements for matters particularly necessary when ground slag is used as a mineral admixture for marine concrete.

[Commentary]

When other parameters, such as the water-binder ratio and mix proportions, are the same as ordinary marine concrete, concrete containing ground slag has the same or higher resistance to sea water and steel-protective capability than concrete containing no ground slag. This has been observed in a number of real concrete structures made using Type B portland blast-furnace slag cement.

Whereas carbonation of concrete containing ground slag tends to proceed faster and slightly deeper than that of concrete made using ordinary portland cement without ground slag, carbonation under marine environment is slower and not as deep as that in air. This has been ascertained in a number of marine concrete structures made using Type B portland blast-furnace slag cement with a cover depth of 70 mm.

12.2 Quality and replacement ratio of ground slag

(1) For marine concrete, a suitable type of ground slag shall be selected from among those conforming to JIS A 6206, so as to provide the required resistance to sea water and steel-protective capability.

(2) The standard replacement ratio of ground slag to be used for marine concrete shall be in the range of 45% to 55%.

[Commentary]

Regarding (1): Aluminum oxide (Al_2O_3) contained in ground slag can react with sulfates penetrating from outside, causing concrete to deteriorate, but this is known to be preventable by adding an adequate percentage of gypsum to ground slag in advance. As sea water normally contains sulfate ions (SO_4^{2-}) of about 2650 mg/ℓ , it is desirable that ground slag to be used for marine concrete contain gypsum equivalent to sulfur trioxide of not less than 2%.

Regarding (2): In order to obtain concrete that has a high resistance to sea water and causes little difficulty in placing, the standard replacement ratio is required to be in the range of 45% to 55% when ground slag 4000 is used, based on the field experience of Type B portland blast-furnace slag cement. In the case of ground slags 6000 and 8000, a replacement ratio exceeding 55% may be specified on the basis of reliable data with reference to the desirable ranges given in Table C 2.2.2.

12.3 Concreting work

When using ground slag for marine concrete, concreting work shall be carried out with care, particularly in regard to curing.

[Commentary]

Premature contact with sea water can adversely affect the durability of concrete containing ground slag. Special care should therefore be exercised to avoid this particularly in the case of off-shore construction.

CHAPTER 13 PAVEMENT CONCRETE

13.1 Scope

This chapter provides the general requirements for matters particularly necessary when using ground slag as a mineral admixture for pavement concrete.

[Commentary]

Pavement concrete normally refers to concrete of the surface course. However, the heavy traffic in recent years has led to an increase in the number of bases stabilized with cement. For this reason, this chapter also covers cement-treated base courses as pavement concrete.

Cement-treated base courses, high-strength base courses of lean-mix concrete, and concrete bases covered with an asphaltic concrete surface course are protected from water loss and not exposed to weather or abrasion while in service. The use of ground slag is therefore considered to be effective for these applications as well.

13.2 Type and replacement ratio of ground slag

The type and replacement ratio of ground slag shall be selected so that concrete with the required qualities can be obtained.

[Commentary]

It is desirable that the replacement ratio be not less than 50% for the purpose of reducing the temperature rise due to heat of hydration, not less than 40% for the purpose of suppressing alkali-silica reaction, and in the range of 30% to 60% for the purpose of increasing strength (see Table C 2.2.2). In the case where ground slag is used for stabilizing bases, the mix proportions may be selected adequately with a high ground slag replacement ratio, as the strength required of such bases is not as high as that of surface courses.

13.3 Concreting work

When using ground slag for pavement concrete, care should be exercised for concreting work, particularly in regard to curing.

[Commentary]

It is advisable to continue curing, during which the surface course is constantly maintained wet, until the flexural strength of concrete attains 70% of the proportioning strength, as in the case of using concrete containing no ground slag. This period should be determined by testing, but when no test is to be conducted, 21 days and 16 days may be applied as the standard to concretes containing ground slag 4000 or 6000 and ground slag 8000, respectively, though dependent on the replacement ratio and air temperature.

In the case of cement-treated bases, which are sufficiently roller-compacted, light traffic immediately after compaction causes no trouble, unless the working vehicles are heavier than the compacting rollers. However, care should be exercised not to damage the surfaces of bases.

It is difficult to obtain the required strength of concrete containing ground slag, if it is placed in cold weather. The temperature of concrete during placing and roller-compaction should therefore be in the range of 7 to 20℃. Placed concrete should also be maintained at 7℃ or higher where practicable during curing. Surface course concrete must be protected from freezing until its compressive strength attains 5 N/mm^2.

CHAPTER 14 DAM CONCRETE

14.1 Scope

This chapter provides the general requirements for matters particularly necessary when using ground slag as a mineral admixture for dam concrete.

[Commentary]

Dams are particularly important huge structures compared with concrete structures in general, and are required to withstand severe climatic environments while retaining the required strength, durability, and watertightness for a long time. The use of ground slag as a mineral admixture is considered to impart to dam concrete comparable or higher qualities regarding these requirements than without it.

14.2 Type and replacement ratio of ground slag

(1) Type and replacement ratio of ground slag to be used for dam concrete shall be selected so that concrete with the required qualities can be obtained.

(2) When using ground slag 4000 conforming to JIS A 6206, its activity index at seven days may be below the specified value, provided it is ascertained by testing that concrete with the required qualities are obtained.

[Commentary]

Regarding (1): Ground slag 4000 is generally used for dam concrete, but ground slag 6000 may also be used at an adequate replacement ratio under cold weather conditions.

Regarding (2): Ground slag 4000 that does not meet the JIS requirement for 7-day activity index is rather preferable where the principal purpose of using ground slag is to reduce the temperature rise of concrete and no high early strength is required as in the case of dam concrete. For this reason, ground slag with a 7-day activity index below the specified value is permitted in the present Recommendations, if it is ascertained by testing that concrete with the required qualities are obtainable.

14.3 Mix proportions

Mix proportions of dam concrete shall be selected so as to minimize the temperature rise of concrete within the range of providing the required strength, durability, water-tightness, and resistance to cracking, as well as the specified workability.

[Commentary]

The binder content may be the same as that of dam concrete containing no ground slag. The replacement ratio should preferably be in the range of 50% to 70% for internal concrete and not more than 60% for external concrete. It should be noted that when more than 60% of cement is replaced with ground slag, it should be confirmed by testing, as a rule, that concrete with the required qualities can be obtained.

14.4 Concreting work

When using ground slag for dam concrete, concreting work shall be carried out with particular care in regard to curing of concrete.

[Commentary]

Dam concreting is in most cases carried out in a severe environment. Care should be exercised for curing in cold weather concreting. A large amount of ground slag can significantly hamper early strength development. Care should therefore be taken, as this could adversely affect the entire construction process including "green cutting" of lift surfaces before placing the next lift.

As temperature rise is anticipated due to hydration heat, dam concreting may be carried out when the daily mean temperature is above 4℃. When the daily mean temperature is in the range of 0 to 4℃, concreting may be carried out with the concrete placing temperature being at 5℃ or higher, provided that sufficient curing is done.

CHAPTER 15 HIGH STRENGTH CONCRETE

15.1 Scope

This chapter provides the general requirements for matters particularly necessary when ground slag is used as a mineral admixture for high strength concrete.

[Commentary]

General requirements for matters particularly necessary for design and construction of high strength concrete are provided in JSCE Recommendations for Design and Construction of High Strength Concrete Structures (Draft).

15.2 Type and replacement ratio of ground slag

The type and replacement ratio of ground slag shall be selected so as to obtain concrete with the required qualities.

[Commentary]

When using ground slag for high strength concrete, ground slags 6000 and 8000 with a high strength-developing capability are generally selected. The recommended replacement ratios for ground slags 6000 and 8000 are 30% to 50% and 30% to 60%, respectively.

Due to the low water-binder ratio, hydration-induced autogenous shrinkage of high strength concrete containing ground slag increases as the replacement ratio increases. With certain mix proportions and curing methods, this could increase the risk of cracking due to hydration heat and drying shrinkage. For this reason, the mix proportions, such as the water-binder ratio, and curing method should be taken into account when selecting the type and replacement ratio of ground slag, so as to obtain the required performance.

15.3 Production, placing, and curing

(1) When using ground slag for high strength concrete, a suitable mixer shall be selected and an adequate batch size and mixing time shall be established, so that concrete can be thoroughly mixed.

(2) When using ground slag for high strength concrete, particular care shall be exercised in regard to curing so as to prevent deleterious cracking.

[Commentary]

Regarding (1): Insufficient mixing not only produces nonuniform concrete but also could hamper the attainment of the required strength. Ground slags 6000 and 8000 are particularly fine and tend to increase the viscosity of the mixtures. It is therefore important to use a suitable mixer and carry out thorough mixing.

CHAPTER 16 SUPERWORKABLE CONCRETE

16.1 Scope

This chapter provides the general requirements particularly necessary when ground slag is used as a mineral admixture for superworkable concrete.

[Commentary]

Superworkable concrete is defined as "concrete having a significantly improved fluidity and retaining the segregation resistance intact while fresh." As this type of concrete has been newly developed, no recommendations or guidelines are available yet. However, as ground slag has been applied to superworkable concrete for in-situ placing and precast products in a number of instances, this chapter describes the points to note when using ground slag for superworkable concrete.

16.2 Mix proportions

(1) Mix proportions of superworkable concrete shall be selected adequately so as to provide the required fluidity, segregation resistance, strength, durability, watertightness, resistance to cracking, and steel-protective capability.

(2) When using ground slag for superworkable concrete, the type and replacement ratio of ground slag shall be adequately selected so as to provide the required superworkable concrete.

[Commentary]

Regarding (2): The use of ground slag for superworkable concrete generally reduces the required dosage of a superplasticizer or air-entraining and high-range water-reducing agent.

The addition of ground slag 6000 or ground slag 8000 easily improves the segregation resistance of concrete when it is fluidized to the required level, and may also improve the qualities of fresh concrete. Ground slag 6000 is mostly used with a replacement ratio of 30% to 70%, whereas ground slag 8000 is used with a replacement ratio of 30% to 60%, partly with the aim of increasing the strength.

Reducing the water-binder ratio to control the viscosity of fresh concrete increases the binder content, increasing the generation of hydration heat, and this can increase the risk of temperature cracking. When ground slag is used for the purpose of suppressing such hydration heat, ground slag 4000 in place of 50% to 70% of cement is used in most cases.

16.3 Production, placing, and curing

(1) Superworkable concrete shall be produced, placed, and cured under careful control according to a specially formulated plan.

(2) When using ground slag for superworkable concrete, special care shall be exercised in regard to curing of concrete.

[Commentary]

Regarding (1): Though the risk of clogging during pumping is small, the pumping resistance of superworkable concrete tends to be higher than in the case of ordinary concrete.

The lateral pressure of superworkable concrete acting on the formwork is significantly higher than that of ordinary concrete. Failure of formwork can therefore have a serious impact. This should be taken into account when designing formwork for superworkable concrete.

Regarding (2): As superworkable concrete has little bleeding water, it is vulnerable to plastic cracking when the surfaces become dry after placing. Also, when ground slag 6000 or ground slag 8000 is used, autogenous shrinkage associated with hardening increases as the replacement ratio increases, leading to a higher risk of cracking due to hydration heat and drying shrinkage. Accordingly, it is important to formulate an adequate curing plan, such as sufficient moist curing, to prevent such deleterious cracking and obtain the required qualities after hardening.

CHAPTER 17 CONCRETE PRODUCTS

17.1 Scope

This chapter provides the general requirements for matters particularly necessary when using ground slag as a mineral admixture for concrete products.

[Commentary]

In addition to increasing the resistance to sea water, ground slag is used for concrete products for the purpose of increasing the strength of concrete and utilizing the concrete as a superworkable concrete. When utilizing concrete as a high strength concrete or superworkable concrete, refer to Chapters 15 and 16 as well.

17.2 Curing

When using ground slag for concrete products, special care shall be exercised in regard to curing of concrete.

[Commentary]

Drying shrinkage can be prevented and long-range improvement of qualities can be expected, if sufficient moist curing is done without drying the members during the period of heat curing, such as steam curing, and thereafter. Autoclave curing has never been applied to concrete products containing ground slag.

CHAPTER 18 OTHER SPECIAL CONCRETES

18.1 General

When using ground slag for swelling concrete, underwater concrete, prepacked concrete, and shotcrete, the type and replacement ratio of ground slag shall be adequately selected, and proportioning, production, placing, and curing shall be carried out adequately so as to ensure the qualities required of each type of concrete.

JIS A 6206-1995

Ground granulated blast-furnace slag for use in concrete

1. Scope

This Japanese Industrial Standard specifies ground granulated blast-furnace slag for use as a mineral admixture in concrete or mortar.

Remark: The standards referred to in this standard are as follows:

JIS A 1108 Method of test for compressive strength of concrete
JIS A 1132 Method of making and curing concrete specimens
JIS R 5201 Physical testing methods for cement
JIS R 5202 Method for chemical analysis of portland cement
JIS R 5210 Portland cement
JIS R 9151 Natural gypsum for cement
JIS Z 1505 Cement craft paper bag
JIS Z 8401 Rules for rounding off of numerical values
JIS Z 8801 Test sieves
JIS Z 9001 General rules for sampling inspection procedures

2. Definitions

Some of the terms used in this standard are defined as follows:

(1) Granulated blast-furnace slag: The material formed when molten blast-furnace slag produced simultaneously with pig iron in a blast furnace is rapidly chilled by water-jet.

(2) Ground granulated blast-furnace slag (Ground slag): The material formed by drying and grinding granulated blast-furnace slag with or without the addition of gypsum.

(3) Reference mortar: Ordinary portland cement mortar for use as the reference in the quality test of ground slag.

(4) Test mortar: Mortar made with a 50-50 mass combination of ordinary portland cement and ground slag in the quality test of ground slag.

(5) Activity index: The percent ratio of the compressive strength of test mortar to that of reference mortar.

(6) Flow value ratio: The percent ratio of the flow value of test mortar to that of reference mortar.

3. Classification

Ground slag is classified by specific surface into the following 3 types:

(1) Ground slag 4000
(2) Ground slag 6000

(3) Ground slag 8000

4. Qualities

The qualities of ground slag shall be as prescribed in Table 1.

Table 1 Qualities of ground slag

Quality \ Type		Ground slag 4000	Ground slag 6000	Ground slag 8000
Specific gravity		≧2.80	≧2.80	≧2.80
Specific surface cm^2/g		≧3000 and <5000	≧5000 and <7000	≧7000 and <10000
Activity index %	7 days	≧55(1)	≧75	≧95
	28 days	≧75	≧95	≧105
	91 days	≧95	≧105	≧105
Flow value ratio %		≧95	≧95	≧90
MgO %		≦10.0	≦10.0	≦10.0
SO_3 %		≦4.0	≦4.0	≦4.0
Ignition loss %		≦3.0	≦3.0	≦3.0
Chloride ions %		≦0.02	≦0.02	≦0.02

Note: (1) This value may be changed by agreement between the supplier and the purchaser.

5. Raw materials

5.1 Granulated blast-furnace slag

Granulated blast-furnace slag with a basicity[2] of not less than 1.60 shall be used.

Note [2]: The basicity shall be calculated by the following equation. The method of determining each constituent shall conform to JIS R 5202. Samples shall be ground to have an approximate specific surface of 4000 cm^2/g.

$$b = \frac{CaO + MgO + Al_2O_3}{SiO_2}$$

where b = basicity

CaO = calcium oxide content in granulated blast-furnace slag (%)

MgO = magnesium oxide content in granulated blast-furnace slag (%)

Al_2O_3 = aluminum oxide content in granulated blast-furnace slag (%)

SiO_2 = silicon dioxide content in granulated blast-furnace slag (%)

5.2 Gypsum

Natural gypsum for cement specified in JIS R 9151 or an equivalent material shall be used.

6. Production method

Ground slag shall be produced by drying and grinding granulated blast-furnace slag. When gypsum is to be added, granulated slag shall be mixed with an appropriate addition of gypsum and ground together. Alternatively, granulated slag and gypsum ground separately shall be blended at the specified proportions and thoroughly mixed.

When using an auxiliary for grinding, it shall be confirmed that the auxiliary has no adverse effect on the qualities of the resulting ground slag. The dosage of the auxiliary shall be not more than 1% of the mass of ground slag.

7. Test methods

7.1 Sampling

The following sampling procedures shall be used:

(1) Take an appropriate amount[3] of ground slag so as to represent the average quality of the test unit and reduce.
The sampling and reducing methods shall be established by consultation between the supplier and the purchaser.

Note [3]: An appropriate amount refers to an amount that leaves 10 kg or more of the sample after reducing.

(2) Samples taken and reduced shall be sifted with an 850 μm sieve specified in JIS Z 8801 to remove foreign matter and stored in moistureproof airtight containers. When testing, samples shall be brought into the laboratory in advance so that the sample temperature may be the same as the room temperature.

7.2 Specific gravity

The test for specific gravity shall conform to JIS R 5201, Section 6 (Specific gravity test). However, the quantity of a test sample shall be 90 g.

Reference: Care should be exercised, as deaeration is more difficult than in the case of cement.

7.3 Specific surface

The test for specific surface shall conform to JIS R 5201, Section 7.1 (Specific surface area test). However, the mass of a test sample shall be such that it can be filled into the cell of Blaine's air permeability apparatus with a similar pressure as on a standard cement sample.

7.4 Activity index and flow value ratio

The tests for the activity index and flow value ratio shall conform to the appendix.

7.5 Magnesium oxide

The method of determining the magnesium oxide content shall conform to JIS R 5202, Section 12 (Determination of magnesium oxide).

7.6 Sulfur trioxide

The method of determining the sulfur trioxide content shall conform to JIS R 5202, Section 13 (Determination of sulfur trioxide).

7.7 Losses by ignition

The method of determining the losses by ignition shall conform to JIS R 5202, Section 6 (Determination of ignition loss). However, the heating temperature shall be 700 ± 50℃.

7.8 Chloride ions

The method of determining the chloride ion content shall conform to JIS R 5202, Section 19 (Determination of chlorine).

Remark: The determination of magnesium oxide and chloride ions may be in accordance with JIS R 5202, Appendix (Method for chemical analysis of portland cement).

8. Inspection

Ground slag shall be sampled by a rational sampling method and tested as stipulated in Chapter 7. Those satisfying the requirement of Chapter 4 shall be accepted. The inspection lot size shall conform to JIS Z 9001 or be established by agreement between the supplier and the purchaser.

9. Packaging

Ground slag shall be packaged in cement craft paper bags specified in JIS Z 1505.

10. Marking

The following shall be marked on the bag when ground slag is shipped in bags or on the delivery sheet when it is shipped in bulk. The date of shipment may be marked by an appropriate form by agreement between the supplier and the purchaser.

(1) Designation (ground granulated blast-furnace slag for concrete)
(2) Type (Ground slag 4000, for instance)
(3) Net mass
(4) Name or abbreviated name of manufacturer

11. Report

The manufacturer shall submit a test report at the request of the purchaser. The form for the test report shall be, as a rule, as shown in Table 2.

Table 2 Form for test report

Ground Slag Test Report					
Year Month		Name of manufacturer			
Quality \ Type		Ground slag 4000	Ground slag 6000	Ground slag 8000	
		Requirement by JIS A 6206			Test value
Specific gravity		≧2.80			
Specific surface cm^2/g		≧3000 and <5000	≧5000 and <7000	≧7000 and <10000	
Activity index %	7 days	≧55(1)	≧75	≧95	
	28 days	≧75	≧95	≧105	
	91 days	≧95	≧105	≧105	
Flow value ratio %		≧95	≧95	≧90	
MgO %		≦10.0			
SO_3 %		≦4.0			
Ignition loss %		≦3.0			
Chloride ions %		≦0.02			

Note: (1) This value may be changed by agreement between the supplier and the purchaser.
Remark: 1. Gypsum addition: yes / no
2. Test value of granulated slag basicity: (not less than 1.60)

Contact: Company name/department in charge
Address
Phone number

APPENDIX
Test methods for activity index and flow value ratio of ground slag using mortar

1. Scope

This appendix specifies the test methods for the activity index and flow value ratio of ground slag using mortar.

2. Appliance

The test appliance shall be as specified in JIS R 5201. However, the molds to be used for fabricating compression test specimens shall be metal cylinders 5 cm in inner diameter and 10 cm in height, and the tamping rod shall be a round steel bar 9 mm in diameter with a blunt tapered end.

3. Materials for test

3.1 Cement

The cement shall be a blend of three brands, in equal parts, of ordinary portland cements from different manufacturers that are arbitrarily selected. Each cement of the blend shall conform to JIS R 5210.

3.2 Fine aggregate

The fine aggregate shall be a 2:1 blend by mass of silica sand with a grading conforming to Appendix table 1 and standard sand specified in JIS R 5201.

Appendix table 1 Grading of silica sand

Nominal sieve size[1] mm	2.5	1.7	1.2	0.6	0.3	0.15
Mass percentage passing the sieve %	100	100~98	97~87	50~40	10~5	0

Note: (1) The nominal sieve sizes correspond to those of the test sieves of metal wire cloth specified in JIS Z 8801, 2.36 mm, 1.7 mm, 1.18 mm, 600 μm, 300 μm, and 150 μm, respectively.

3.3 Water

Water shall be purified water or service water.

4. Sampling

Samples taken and reduced in accordance with Section 7.1 of the body text shall be used.

5. Test methods

5.1 Preparation of mortar

5.1.1 Proportioning

The mix proportions of mortars shall be as specified in Appendix table 2.

Appendix table 2 Mix proportions of mortars in g

Type of mortar	Cement	Sample	Fine aggregate	Water
Reference mortar	500	–	1250	250
Test mortar	250	250		

Reference: Appendix table 2 gives the amount of one batch, which will produce mortar sufficient for 4 specimens or 2 flow tests.

5.1.2 Mixing

Fix the mixing bowl and paddle at the mixing position. Charge the bowl with water. Add cement in the case of reference mortar or cement and a sample in the case of test mortar, and mix for 40 seconds at a low speed. While mixing, add 1,250 g of fine aggregate by small parts. Stop mixing for 20 seconds, during which time scrape off the mortar adhering to the wall of the bowl and the paddle with a spoon. Mix finally for 2 minutes at a high speed.

5.2 Compression test

5.2.1 Fabrication of specimens

(1) Mix three batches each of reference mortar and test mortar, and fabricate four specimens from each batch.

(2) Place the mortar in the molds in two layers. Rod each layer 25 strokes with a tamping rod. If voids are left by the tamping rod, tap the side of the mold lightly to close the voids.

(3) Finish the top surface in accordance with JIS A 1132, Section 4.4 (Top surface finishing of specimens) and carry out mold removal and curing in accordance with JIS A 1132, Chapter 7 (Form removal and curing). Cap the specimens after 6 hours from placing, where applicable.

5.2.2 Compression test

Compression tests shall be conducted in accordance with JIS A 1108. The number of specimens for each test age shall be 4. At least one specimen from each batch shall be included at each test age. The test age shall be 7, 28, and 91 days.

5.3 Flow test

The flow test shall conform to JIS R 5201, Section 10.7 (Flow test).

6. Calculation of activity index and flow value ratio

6.1 Activity index

The activity index at each age shall be calculated by the following equation to an integer in accordance with JIS Z 8401:

$$A_s = \frac{c_2}{c_1} \times 100$$

where A_s = activity index (%)

c_1 = average compressive strength of 4 specimens of reference mortar at each age (N/mm^2)

c_2 = average compressive strength of 4 specimens of test mortar at each age (N/mm^2)

6.2 Flow value ratio

The flow value ratio shall be calculated by the following equation to an integer in accordance with JIS Z 8401:

$$F = \frac{l_2}{l_1} \times 100$$

where F = flow value ratio (%)

l_1 = flow value of reference mortar

l_2 = flow value of test mortar