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

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

Shigeyoshi NAGATAKI, Chairman

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SYNOPSIS

The Concrete Committee of the Japan Society of Civil Engineers (JSCE) organized Subcommittee in 1985 for the Research on the use of ground granulated blast-furnace slag (ground slag) as an admixture when JSCE was entrusted to make researches and recommendation for design and construction of concrete mixed with ground slag by related corporation. After the subcommittee had made extensive researches, recommended practice was drawn up in 1988 on the basis of the results of research works. The recommended practice includes recommendation on the use of ground slag as an admixture and JSCE standards on quality and test methods for ground slag.

Shigeyoshi NAGATAKI, Chairman

Shigeyoshi NAGATAKI is professor of Tokyo Institute of Technology, Tokyo. He received his Doctor of Engineering Degree from the University of Tokyo in 1966. Currently, much of his research work has been on slag, fly ash, expansive cement, superplasticizer, and torsion of reinforced concrete. He has written some 100 papers on these subjects. He is a member of JSCE, JCI, AIJ, RILEM and a fellow of ACI.

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CONTENTS

RECOMMENDATION FOR DESIGN AND CONSTRUCTION OF CONCRETE

CONTAINING GROUND GRANULATED BLAST-FURNACE SLAG AS AN ADMIXTURE

CHAPTER 1 GENERAL

1.1 Scope of Application

(1) This recommendation provides general requirements which are particularly required for design and construction of concrete using ground granulated blast-furnace slag (hereafter simply called "ground slag") as an admixture. The items which are not included in this recommendation shall be in accordance with JSCE "Standard Specification for Design and Construction of Concrete Structures".

(2) The standard quality of the ground slag specified in this recommendation shall conform to the requirements of JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete" and the specific surface areas shall be between 2,750 and 6,000 cm^2/g.

(3) The replacement ratio of cementitious material by ground slag shall be in the range of 30 to 70 percent by weight.

[Commentary on 1.1]

This recommendation provides the general requirements to concrete structures using ground slag as an admixture. The concrete structures can be non-reinforced concrete, reinforced concrete, and prestressed concrete structures including concrete slabs for pavements and concrete dams. The ground slag to be used shall satisfy the JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete" and shall have, in principle, a specific surface area ranging from 2,750 to 6,000 cm^2/g measured by modified Blaine test. The replacement ratio of ground slag i.e., the weight ratio of ground slag to total cementitious materials per unit volume of concrete, shall in principle be within 30 to 70%.

Ground slag has been used in Japan since 1910's as a material for slag cement. Utilization of ground slag as an admixture to concrete has been already established in other countries such as the United Kingdom, the United States, and Canada, and the amount of the ground slag used in these countries as an admixture for concrete has increased to a large extent. The advantage to use ground slag as a material for slag cement is its ease of handling. However, until now, no established standards or provisions stipulated the quality of ground slag itself in Japan, although there were some standards stipulating the properties of cement as a whole. In addition, there were no standards which clearly specified the exact amount of ground slag to be used, causing inconvenience in a number of cases where ground slag was to be used for special purposes. Recently in Japan, with the establishment of manufacturing and sales systems for ground slag, the use of the slag has been gradually increasing. Under such circumstances, the Japan Society of Civil Engineers specified the Standard "Ground Granulated Blast-Furnace Slag for Concrete" in October, 1986, which stipulate the rules for using ground slag as an admixture, and also added some provisions covering the use of ground slag to the "Standard Specifications for Design and Construction of Concrete Structures". This Recommendation was established based on the Standard Specifications, and is applicable to all the concrete structures taken up in the Standard Specifications.

Mixing an appropriate amount of ground slag of adequate quality into concrete gives rise to several favorable effects. They include: (1) control over temperature increases due to the heat of cement hydration ; (2) control over the alkali-aggregate reaction; and (3) improvement in chemical resistance against sulfates or sea water. As the effects obtained in practice, however, greatly differ with the quality and the replacement ratio of ground slag, it is important to carefully determine the quality and the replacement ratio according to each specific purpose of use.

The fineness of ground slag is one of the critical factors determining the quality. Some of the ground slag products on the market satisfy the JSCE's Standard "Ground Granulated Blast-Furnace Slag for Concrete" but have the fineness value more than 8,000 cm^2/g. The finer the slag the higher the hydration, and therefore improves the strength of concrete containing the slag at early ages. The properties of the ground slag with high fineness are considerably different from those of ground slags powders with fineness less than 6000 cm^2/g, and actual records of work using the ground slag with a high fineness are scarce. For these reasons, this recommendation do not apply to ground slag with a high fineness.

On the contrarily, there are some ground slag products with a fineness near the lowest values of JSCE standards and which satisfy all the specified items except for the strength properties (activity index) at the age of 7 days. As this type of ground slag is suitable for concrete to be used for dam construction which does not require high early strength but lower heat of hydration, it was determined that this type of ground slag can be used for dam concrete as specified in Chapter 15 hereof.

The necessary replacement ratio (by weight) of cement by ground slag differ with the purpose of use. Generally, no special effects are exhibited when the replacement ratio is less than 30%. The larger the replacement ratio, the more obvious the effects are. When the replacement ratio is too large, however, special care is required for curing and other processes. Also, actual results of studies or performance records which can be used as reference are scarce. The range of the replacement ratio from 30 to 70% adopted in this Recommendation was determined with these points taken into consideration. When ground slag is to be used for special structures not subject to this Recommendation, such as to use ground slag with a fineness of 8,000 cm^2/g

or more, or to use concrete with the replacement ratio beyond the specified range of 30 to 70%, it is necessary to carry out thorough investigations and examinations with this Recommendation as reference.

It should be noted, moreover, that the effects of the use of ground slag are affected to a large extent by the temperature of concrete at the time of placement as well as the duration and method of curing in addition to the replacement ratio. Generally, when ground slag is used, it is necessary to allow a longer period of time for moist curing than when only portland cement is used. Insufficient moist curing will not only result in failure to attain the expected effects but also may cause the quality of the concrete to be inferior to other concretes. It should also be noted that the effects will be influenced by the type of cement of concrete in which ground slag is mixed.

1.2 Definitions

The following terms are defined for general use in this Recommendation.

Ground granulated blast-furnace slag (Ground slag): Dried ground granulated fine powder of slag obtained from the blast-furnace and cooled either by water or air. Ground slag with addition of gypsum dehydrate is also included.

Cementitious material: A general term for material including cement and mineral admixtures such as ground slag and fly ash.

Replacement ratio: The ratio of the weight of ground slag to the weight of total cementitious material per unit amount of paste, mortar or concrete. The replacement ratio is generally expressed as a percentage.

Water-cementitious material ratio: The value of the weight of water in paste calculated with the assumption of saturated surface-dry state of aggregate divided by the sum of weight of cementitious material in fresh mortar or concrete. The water-cementitious materials ratio is generally expressed as a percentage.

Fineness of ground slag: The fineness of ground slag measured by the test method expressed in the section 6.2 of the JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete". The fineness is expressed by means of specific surface area (cm^2/g).

Basicity of ground slag: The value obtained from the following equation using the test results obtained through chemical analysis of ground slag in accordance with the section 5.2 of the JSCE Standard "Blast-Furnace Slag Fine Powder for Concrete".

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

Activity index of ground slag: The ratio of compressive strength of mortar using ground slag to the compressive strength of mortar made of base cement in accordance with the test method specified in section 7.1 of the JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete".

[Commentary on 1.2]

Ground slag: Blast-furnace slag can roughly be divided into two different types according to the methods for cooling the molten slag discharged from blast furnaces : crystalline slag obtained by annealing and granulated slag obtained by quenching. Only quenched slag is ground into a powder to produce ground slag. This Recommendation is applicable only to such ground granulated blast-furnace slag products so manufactured.

Cementitious material: Cementitious materials generally include cement which binds aggregates or other similar mineral powdered materials mixed into concrete. In this Recommendation, a material consisting of cement, ground slag, fly ash and other similar mineral admixtures is called a cementitious material.

Basicity: Basicity of ground slag indicates the total weight percentage of CaO, MgO, and Al_2O_3 to the weight percentage of SiO_2. When the basicity is high, as the content of SiO_2 is small, the ground slag is unstable from the crystallographic point of view. This means the reactivity of slag is large. According to the results of experiments on mortar and concrete, the higher the basicity, the larger the initial strength. The results also show, however, that the long-term strength will not always be high when the basicity reaches a certain point.

Some ground slags contain gypsum. The basicity (b) of ground slag can be estimated from the following equation (approximate expression when SO_3 is not more than 3%) based on the results of chemical analyses.

$$b = \frac{CaO + MgO + Al_2O_3}{SiO_2} - 0.07\frac{SO_3 - 0.04}{SiO_2}$$

Activity index: The activity index is one of the important indices indicating the quality of ground slag, and is used to evaluate the quality by the strength properties of ground slag using mortar. For example, when the activity index at the age of 7 days is large, the initial strength of concrete using the ground slag as an admixture is large and the heat of hydration is high. Contrarily, when the activity index is small, the initial strength is small and the heat of hydration is low.

CHAPTER 2 QUALITY OF CONCRETE CONTAINING GROUND SLAG AS AN ADMIXTURE

2.1 General

Concrete containing ground slag as an admixture shall have the required quality with minimum variation.

[Commentary on 2.1]

Concrete which contains ground slag has properties somewhat different from those of ordinary concrete. When concrete containing ground slag is to be used, it is necessary to thoroughly understand these properties so that the required strength, durability, water-tightness, and other properties to protect reinforcing bars can be attained and so that the quality will fluctuate less.

Brief explanations on the properties of concrete containing ground slag as an admixture and the points to be noted when the concrete is to be used are explained below.

(1) Properties of concrete containing ground slag

Fresh concrete: The addition of ground slag shall not change the slump of concrete; the addition somewhat increases the slump compared to concrete without it. To produce concrete with the same slump as ordinary concrete, therefore, unit water content should be reduced.

The addition of ground slag tends to reduce the air content of concrete. In order to produce concrete with the same air content as ordinary concrete, the amount of air-entraining agent should be increased. This tendency is more obvious when the replacement ratio of ground slag is large or the fineness of ground slag is high.

Bleeding tends to be less than ordinary concrete not containing ground slag when ground slag with a fineness over 4,500 cm^2/g is added at a high replacement ratio. There will be no great differences between ordinary concrete and concrete containing ground slag with a fineness between 3,500 and 4,500 cm^2/g. When the fineness is less than 3,500 cm^2/g, bleeding tends to increase.

The time required for concrete to set tends to be increased when ground slag is added, and both initial and final setting tend to be delayed.

Both the bleeding and setting time of concrete containing ground slag are, as compared to ordinary concrete, liable to be affected by the temperature of the concrete when mixed. The lower the temperature, the higher the bleeding and the longer the setting time.

Development of strength: The development of the strength of concrete containing ground slag is affected particularly by curing conditions and the quality and the replacement ratio of ground slag, among other factors. When ground slag with a low fineness is used, the initial strength is generally low. For example, the compressive strength of concrete containing ground slag with a fineness of less than 4,500 cm^2/g at the age of 7 days after normal curing is smaller than that of ordinary portland cement concrete. The development of the strength of concrete containing ground slag thereafter will be greater than that of ordinary concrete. From a long-term point of view, the strength of concrete will be higher when ground slag is used even if its fineness is low.

The development of the strength of concrete containing ground slag is more affected by the mix temperature and the curing temperature than ordinary concrete. In particular, the development of the long-term strength is unsatisfactory when the mixing temperature is lower than 10°C. Therefore, special care should be taken during curing, etc. when the mixing temperature is lower than 10°C. The development of the strength of concrete containing ground slag is also liable to be affected during curing, especially by dry conditions in initial stages. When the concrete is dried, the generation of strength tends to be inferior. It is necessary, therefore, to provide thoroughly wet conditions during curing.

The relationship between the compressive strength and the tensile strength of concrete containing ground slag is similar to that of ordinary concrete. Also, the relationship between the compressive strength and the static coefficient of elasticity is generally similar to that of ordinary concrete although it will differ somewhat with the quality of the ground slag used or curing conditions.

<u>Exothermic characteristics</u>: The exothermic characteristics of concrete containing ground slag are affected by the quality and the replacement ratio of the ground slag. As compared with ordinary portland cement, the reaction speed of ground slag is more affected by the temperature of concrete at the time of placement and the ambient temperature.

The smaller the replacement ratio of ground slag and the higher the mixing temperature, the larger is the increase in the insulation temperature of ground slag. In some cases, the increase is larger than that when only portland cement is used. In this case, however, the lower the fineness of ground slag and the larger the replacement ratio, the slower the exothermic speed when compared with concrete which uses only portland cement. If both the fineness and the replacement ratio are set at appropriate levels, therefore, it is possible not only to delay the time reaches the highest temperature of concrete but also to lower the the highest temperature of the concrete, which are effective in preventing cracks from occurring due to temperature.

<u>Durability</u>: The admixtures with the effects obtained from pozzolona are said to have favorable effects on controlling the alkali-aggregate reaction, and it has been confirmed that ground slag has an alkali-aggregate reaction controlling effect as does fly ash and silica fume. In order to have the same effect, it is necessary for ground slag, as compared with fly ash, to be substituted in a larger replacement ratio. According to the results of tests using mortar bars, the expansion of concrete due to the alkali-aggregate reaction may be controlled if the replacement ratio of ground slag is set over 50% even if the cement with

an alkali content of 1.2%, which is considered to be the highest level in Japan, is used. Under present conditions, since most ordinary portland cement and high-early-strength portland cement on the market have an alkali content of less than 0.8%, setting the replacement ratio of ground slag over 40% is considered effective as a means to control the alkali-aggregate reaction.

As for the characteristics to protect the reinforcing bars in concrete, the permeation of chlorine ions or oxygen and the resistance to neutralization are closely related. It has been clarified from the results of tests on concrete using blast-furnace slag cement type B that the addition of ground slag is effective against the permeation of chlorine ions. Some test results also verify the effectiveness of ground slag against the permeation of oxygen. The neutralization speed of concrete containing ground slag, however, is almost the same or somewhat quicker than that of ordinary concrete. When the replacement ratio is more than 70%, the neutralization speed of concrete containing ground slag will be approximately twice that of ordinary concrete.

When a sufficient concrete covering is assured and the neutralization depth is smaller than the covering depth, the addition of ground slag will be effective in preventing reinforcing steel in concrete structures from being corroded. It has been confirmed from the results of long-term exposure tests conducted in an offshore environment that the reinforcement bars in concrete containing blast-furnace portland blast-furnace slag cement B are less likely to corrode than those embedded in concrete containing ordinary portland cement. The reason is that, since the concrete covering in an offshore structure is generally large, the neutralization effect does not reach the level of reinforcement bars and the resistance against the permeation of chlorine ions and oxygen due to the addition of ground slag is improved.

With regard to the resistance to freezing, concrete containing ground slag performs at least as well as ordinary concrete if it is thoroughly cured as an air-entrained concrete. If not thoroughly cured, the resistance to freezing of concrete containing ground slag will be considerably decreased.

The resistance against sulfates will be substantially improved, as is clear from the actual performance results of blast-furnace slag cement, if the replacement ratio is set higher than 50%.

Water-tightness: The water-tightness of concrete containing ground slag will be small for the first several days as compared with ordinary concrete but will attain almost the same level when a sufficient strength is assured at the age of around 28 days.

Contraction due to drying and creep: It should be considered that the long-term contraction of concrete containing ground slag due to drying will be almost the same as that of ordinary concrete. The contraction due to drying at the age of within one month will be somewhat larger than that of ordinary concrete. Insufficient curing may result in a considerable increase in contraction.

The creep of concrete containing ground slag will be smaller than that of ordinary concrete. When loads are applied to the concrete at the age of only three days or so, or when the water-cementitious material ratio is around 70%, care should be taken as the creep of concrete containing ground slag tends to be greater than ordinary concrete. As in the case of the contraction due to drying, the extent of creep will be considerably increased if curing is insufficient.

Color: Concrete containing ground slag may be tinged with a color different from that of ordinary concrete after it has been mixed or hardened because of the characteristics or the components of ground slag. Since ground slag is whiter than cement, concrete containing blast-furnace portland blast-furnace slag cement will be whiter in many cases than ordinary concrete when it is mixed. For a few weeks from several days after hardening, concrete containing ground slag will be bluish due to the effect of the iron sulfide contained in ground slag. This period will be longer in water or sea water. Afterwards, however, the bluish color will fade due to oxidization and concrete containing ground slag will finally become whiter than ordinary concrete.

(2) Precautions in construction

Curing is the most important process over which care should be exercised during construction using concrete containing ground slag. When ground slag is present, the hydration speed of concrete containing ground slag will be slower than that of concrete containing ordinary portland cement and it will take longer for the former type of concrete to hydrate. Therefore, as compared with ordinary concrete, wet curing, especially curing during the initial stages, greatly affects the quality of concrete obtained when it has hardened.

Commentary Table 2.1 shows the qualitative degree of curing as a reference. The standards and provisions as to general curing are given in Chapter 6, "Curing of Concrete".

Commentary Table 2.1 Reference table indicating the relationship between the degree of curing and the quality and the replacement ratio of ground slag

Quality Substitution rate	Fineness Low <-> High	Activity index Small <-> Large
30 ~ 40%	I	I
40 ~ 55%	III<->II	III<->II
55 ~ 70%	IV <->III	IV <->III

Note) Symbols I to IV indicate the degree of curing. The greater the number, the more care shall be exercised when curing. In the case of Degree I, however, greater care shall be exercised than when ordinary portland cement is used.

2.2 Selection of Ground Slag and Replacement Ratio

When ground slag is used as an admixture for concrete, the selection of the ground slag to be used and determination of the replacement ratio of the slag shall be done so as to meet the required properties of concrete.

[Commentary on 2.2]

As explained in the commentary on 2.1 above, concrete containing ground slag has various characteristics which are different than ordinary concrete. When ground slag is used as an admixture, the aim in many cases is to give concrete properties which can not be expected from ordinary concrete.

Commentary Table 2.2 Desirable extent of replacement ratios

Purpose of use	Desirable extent of replacement ratios
Control of temperature increase due to the heat of hydration	Over 50%
Control of alkali-aggregate reaction	Over 50% *
Improvement in the chemical resistance against sulfates or sea water (incl. salt damage)	Over 40%

* Over 40% when the alkali content of portland cement is less than 0.8%.

Commentary Table 2.3 Desirable quality of ground slag

Purpose of use	Fineness	Activity index
Control of temperature increase due to the heat of hydration	Small	Small
Control of alkali-aggregate reaction	Medium	Medium
Improvement in the chemical resistance against sulfates or sea water (incl. salt damage)	Medium to large	Medium to large

Note: The terms small, medium, and large in the table indicate the degree of fineness and activity index.

Generally, the objectives of the use of ground slag are, as explained in the commentary on 1.1 : (1) to control the temperature increases due to the heat of hydration ; (2) to control the alkali-aggregate reaction ; and (3) to improve the chemical resistance against sulfates or sea water.

When ground slag is used, the quality and the replacement ratio of ground slag must be appropriate for the purposes of use. Until the present, however, no theories have been established as Recommendation and it was difficult to indicate proper quantity. Commentary Tables 2.2 and 2.3 show the qualitative results of previous studies and should be used as reference when determining the quality and the replacement ratio of ground slag according to the purposes of use.

2.3 Strength

(1) In general, the strength of concrete containing ground slag as an admixture shall be expressed by compressive strength tested at the age of 28 days.

(2) In case of applying the concrete for pavements, the strength of the concrete shall be expressed by flexural strength at the age of 28 days.

(3) In case of applying the concrete for concrete dams, the strength of the concrete shall be expressed by compressive strength at the age of 91 days.

[Commentary on 2.3]

Commentary on (1) The compressive strength of concrete containing ground slag as an admixture will be greater than that of ordinary concrete at the age of 28 days and afterwards as long as it has been properly cured. To use the compressive strength at the age of 28 days as a standard strength for concrete containing ground slag, as in the case of ordinary concrete, is considered unreasonable from the engineering point of view. However, it has been used as a standard strength for concrete containing portland blast-furnace slag cement despite the drawbacks. The degree of increase of the compressive strength of concrete containing ground slag differs with the quality and the replacement ratio of the ground slag used. With these points taken into consideration, it was determined that the compressive strength at the age of 28 days of the specimen taken from concrete which had received normal curing would be used as the standard strength of the concrete to be used general structures.

Commentary on (2) and (3) As for the strength of concrete to be used for pavement and dams, the strength at the number of days specified in the JSCE "Standard Specifications for Design and Construction of Concrete Structures" shall apply.

CHAPTER 3 MATERIALS

3.1 General

Materials to be used for concrete shall be of confirmed quality.

[Commentary on 3.1]

When ground slag is to be used as the substitute for cement, it is desirable that not only the materials to be used but also the quality the concrete is expected to attain when these materials are used be confirmed so that the expected effects will result in full. Since the quality of concrete containing ground slag changes with the curing temperature and the replacement ratio of ground slag, it is suggested to check the properties of the concrete by trial mix with the same mix proportion as that to be used for the actual construction under conditions similar to those which will prevail during actual construction to confirm the properties of the concrete.

3.2 Ground Slag

(1) Ground slag shall conform to the requirements of the JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete".

(2) Ground slag to be used for dam concrete shall conform to the requirements of Section 15.2 of this Recommendation.

[Commentary on 3.2]

The JSCE Standard of "Ground Granulated Blast-Furnace Slag for Concrete" stipulates the fluctuation limits of the chemical components, physical properties, activity index, mortar flow value, and fineness as the parameters for determining the quality of the ground slag to be used for concrete. These values were set assuming that ground slag would be used for general concrete structures, and the Standards require the use of only the products which satisfy these Specifications for general concrete structures.

The activity indices were determined on the condition that the development of the strength of the concrete would not greatly be decreased as compared with ordinary concrete. When ground slag is used to control temperature increases of dam concrete, for example, a favorable performance will be expected if a product satisfying all the specified values but with a lower activity index at the age of 7 days than that specified in the Standards is used as explained in Chapter 15, "Concrete for Dams".

The basicity of ground slag is one of the criteria indicating the strength development properties. It is stipulated in the Standards that the basicity of ground slag be not less than 1.4, which is the same as that for blast-furnace slag, an admixture of blast-furnace slag cement.

The basicity of the products on the market ranges from around 1.75 to 1.95. The sulfide (S) and the sulfur trioxide (SO_3) contained in ground slag are stipulated to be not more than 2.0% and 3.0%, respectively. Sulfur trioxide changes with the addition of gypsum ($CaSO_4$), which exerts a complicated effect on coagulation properties and the hydration reaction. An insufficient amount of gypsum will delay the initial reaction of slag and an excessive amount of gypsum will result in a reduction of the long-term strength of concrete and increased contraction due to drying. When the replacement ratio of ground slag is high, it may be necessary to add a certain amount of gypsum. Since some ground slag products on the market contain gypsum and some do not (SO_3 : less than 0.3% or so), it is necessary to check the content of sulfur trioxide indicated in the test certificate to confirm whether the product contains gypsum or not.

The fineness of ground slag is stipulated to be not less than 2,750 cm^2/g. Generally, slag powder products with a fineness from about 3,500 to 4,500 cm^2/g are available on the market. The finer the ground slag, the more its hydration reaction is promoted and the larger the activity index, an indicator of the development of strength. At the same time, however, the exothermic speed will be higher, too. It is therefore necessary to use the products for specific purposes: those with a fineness of less than 3,500 cm^2/g for controlling temperature rise; those with a fineness around 4,000 cm^2/g for general purposes; and those with a fineness of more than 5,000 cm^2/g for the assurance of short-term strength. As those with a fineness around 8,000 cm^2/g have different properties from those with a fineness less than 6,000 cm^2/g, as explained in the commentary on 1.1, it is necessary, when such products are to be used, to thoroughly investigate and examine the whole process including materials, mix proportion, and construction with those Recommendation as a reference.

Usually, ground slag contains alkali such as sodium (Na) and potassium (K), with the total alkali content ($R_2O = Na_2O + 0.658\ K_2O$) being 0.50% on average and 0.70% at the maximum. It is generally said that the alkali metal contained in ground slag hardly elutes, proving its effect on controlling the alkali-aggregate reaction.

The strength development properties of ground slag when it is substituted for cement is expressed by the activity index. The activity index, however, is the standard value indicating the quality of ground slag itself, and the actual strength development properties of concrete containing ground slag will differ from the standard value for ground slag. The strength of concrete containing ground slag differs not only with the type of the cement and the activity index of the ground slag to be used, but also with the replacement ratio, the water-cementitious material ratio, the mix proportion conditions, and the curing conditions. It is suggested, therefore, to examine in advance the quality of the ground slag to be used including the activity index, fineness, and basicity as well as as suitable combination of the replacement ratio with the quality of the materials to be used for construction, the construction conditions, and the structural conditions taken into consideration so that concrete of the required quality can be obtained.

3.3 Cements

(1) Cements shall conform to the requirements of JIS R5210 "Portland Cement", and, as a rule, only ordinary portland cement shall be used. In the case of using either high-early-strength or moderate-heat portland cements, it is necessary to test the strength or heat properties of concrete using ground slag as an admixture.

(2) For cement types conforming the requirements of JIS R5211 "Portland Blast-Furnace Slag Cement", JIS R5212 "Portland Pozzolona Cement" and JIS R5213 "Portland Fly Ash Cement", it is necessary to determine proper methods of their use after investigation.

[Commentary on 3.3]

Commentary on (1) The cement to be used with ground slag shall as a rule be ordinary portland cement. This is because when ordinary portland cement. This is because when ordinary portland cement is used, the properties of concrete containing ground slag can easily be estimated from the results of previous studies and the construction records. As properties such as the development of strength differ with the type of ground slag used, if it is difficult to estimate the properties of the concrete from the existing results of previous studies and construction records, it is desirable to confirm the properties in advance by test-mixing concrete using the same cement and the ground slag to be used for construction. Although ordinary portland cement contains admixtures with on extent less than 5%, there will be no practical effects from substituting it with ground slag.

High-early-strength portland cement is used, even if it is partially substituted with ground slag, when it is required to obtain an initial strength similar to that obtained when only ordinary portland cement is used or to assure a certain level of initial strength when the temperature is low. However, the larger the replacement ratio of ground slag, the weaker the high-early-strengthening property.

The major purpose of mixing ground slag with moderate-heat portland cement is to control the temperature rise of concrete to a larger extent than when only moderate heat portland cement is used. When the replacement ratio is low, the expected effect will not be exerted but the temperature may also rise. In addition, the development of strength may be greatly impeded when the curing temperature is low. When high-early-strength or medium heat portland cement is to be used, it is necessary to carry out tests to confirm whether the expected purpose of the cement will be attained or not.

Commentary on (2) Ground slag may be substituted with blended cements such as portland blast-furnace slag cement and portland fly ash cement. These blended cements are used for the purpose of improving control over the alkali-aggregate reaction and the temperature rise speed, sea water resistance, and chemical resistance.

In the case of concrete using a blended cement, the replacement ratio of the ground slag and the amount of the admixture in the cement are larger, the development of strength and other properties are liable to be affected by the curing conditions. When the temperature is low, not only the development of strength will be delayed but also the increase in the long-term strength will be small, especially when the cross-section is thin. It is therefore very important to insulate the concrete and to thoroughly provide wet curing. When fly ash cement is used, the extent of the decrease in strength due to the substitution of ground slag is relatively low at a curing temperature of around 20°C, and the setting and the development of the strength of concrete will be delayed. When ground slag is used as a substitute for these cements, it is necessary to confirm the setting and the strength development properties and to thoroughly investigate the construction methods such as curing in order to assure the safety of construction and to obtain concrete of the required quality.

When blended concrete is to be used, since the amount of admixtures in the cement differs with the type and the manufacturer of the cement, an appropriate replacement ratio of ground slag to obtain the required performance of concrete can not be determined unless the amount of each admixture contained in the cement to be used is confirmed. It is necessary, therefore, to initially confirm the amount of blast-furnace slag or fly ash contained in the cement to be used with the test certificate or similar documents. When the amount of the admixture contained in cement is unknown, the replacement ratio should be determined assuming that it is equal to the maximum value specified in the provisions of JIS with the safety against the strength development properties taken into consideration.

3.4 Admixtures

Mineral admixtures and chemical admixtures for concrete shall be of confirmed quality. It is necessary to confirm the quality of the admixture, the method of use, and the properties of the concrete when mixed with ground slag by conducting tests prior to the use of the admixture.

[Commentary on 3.4]

Even when ground slag is to be used, it is recommended to use air entraining agents, air entraining water reducing agents, water-reducing agents, or fluidization agents as in the case of ordinary concrete. When provisions as to quality are given in the JIS or JSCE Standards, those satisfying these provisions shall be used. For those provisions for quality not given, the performance should be confirmed with reliable data or tests prior to use. There are admixtures for which the properties of concrete when mixed with them have not been confirmed even if their own performance has been confirmed as favorable. It is, therefore, necessary to initially confirm the quality of the admixture, the method of use, and the properties of the concrete when mixed with the admixture by conducting tests prior to the use of the admixture.

In the case of concrete containing ground slag, the amount of air-entraining agent (the jointly used air-entraining agent in the case of air-entraining water-reducing agent) to be used to entrain the required amount of air tends to increase. When the fineness or the unit amount of ground slag used are large, the effects of water-reducing agents may be considered the same or better than that expected in the case of ordinary concrete. When it takes a considerably long time for concrete to set or to harden, the sulfur trioxide content of the ground slag as well as the type and the amount of the water-reducing agent should be determined based on the results of tests.

When an expansion agent is to be used, portland cement conforming to the provisions of JIS R 5210 shall in principle be used. When fly ash is to be used, it is suggested that fly ash cement containing fly ash be used. When these admixtures are to be used with ground slag, the setting and the strength development properties of concrete may be changed, and the expansion properties of expansion concrete may be changed, too.

CHAPTER 4 MIX PROPORTIONS

4.1 General

Mix proportions of concrete shall be determined so as to reduce the unit water content as much as possible within the range of obtaining adequate workability and developing all properties such as required strength, durability, water-tightness and protection of reinforcements.

[Commentary on 4.1]

The basic rules for mix proportioning of concrete with ground slag are the same as those for ordinary concrete. The dominant principle is to minimize the unit water content. In the case of concrete containing ground slag, it is important to determine the mix proportion so that the expected purposes of the ground slag can be attained in addition to the dominant principle.

4.2 Replacement Ratio

Replacement ratio of ground slag shall be determined, as a standard, within the range of 30% to 70%, considering the predetermined purposes of the use of ground slag.

[Commentary on 4.2]

The replacement ratio of ground slag should be within 30 to 70% with the points explained in the commentary on 3.2 and the commentary tables 2.2 and 2.3 taken into consideration so that the predetermined purposes can be attained.

When ground slag is added to a blended cement, the replacement ratio must be determined with the type and the amount of the admixture in the blended cement taken into consideration. In this case, the replacement ratio should be determined in a manner assures portland cement which can supply hydrogen ions and calcium hydroxide in an amount sufficient to have ground slag, fly ash, and other admixtures act as a binder.

The replacement ratio of the ground slag to be added to a blended cement as an admixture can generally be expressed as follows :

(1) For portland blast-furnace slag cement:

$$G = \frac{R - S}{100 - S} \times 100$$

where, G : replacement ratio of ground slag (%)
R : percentage of the amount of the total blast-furnace slag in the cementitious material (%)
S : substitution rate of the blast-furnace slag as the admixture of portland blast-furnace slag cement (%)

(2) For portland silica and fly ash cements:

$$G = R$$

The maximum limit of ground slag to be added to the blended cement as an admixture can be expressed by the following expression based on the maximum value for the mixing rate of the admixture specified by the relevant provisions of the current JIS Standards.

(1) For portland blast-furnace slag cement:

$$RSg < \frac{70 - S}{100 - S} \times 100$$

where, RSg : limit of replacement ratio of blast-furnace slag powder

(2) For portland fly ash cement:

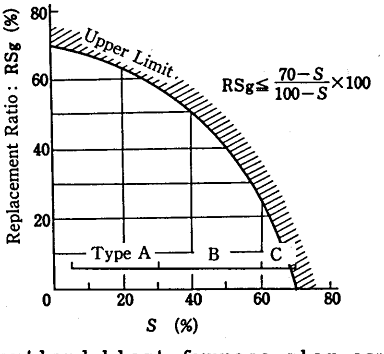
Assuming that the upper limit of the percentage of portland cement and fly ash content required for the fly ash to hydrate would be 0.3, and that the upper limit of the percentage of portland cement and ground slag content required for the ground slag to hydrate would be 0.7.

$$Rsg < \frac{70(30-F)}{30 - 0.7F}$$

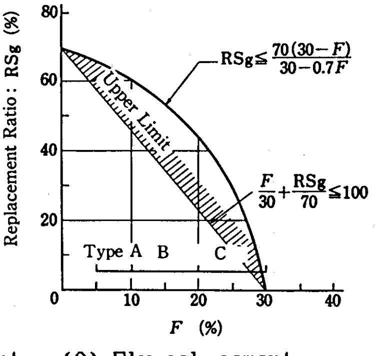
where, F : percentage of fly ash as an admixture of fly ash cement (%)

Since there still remain uncertain points concerning hydration when ground slag is used as the substitute in fly ash cement, the following expression considering safety as indicated by Commentary Fig. 4.2.1(2) is applied in these Recommendation.

When the amount of admixture contained in the cement to be used is unknown, the maximum value specified in the JIS for each type of admixture shall apply.



(1) Portland blast-furnace slag cement



(2) Fly ash cement

Commentary Fig. 4.2.1 Limit replacement ratio of ground slag when a blended cement is used.

4.3 Water-Cementitious Material Ratio

The water-cementitious material ratio shall be determined based on the required strength and durability of concrete. For structures to be water-tight, the water-tightness of concrete shall be also considered.

(1) In the case of determining the water-cementitious material ratio (W/[C+Sg]) based on compressive strength, the following method shall be employed.

(a) In principle, the relation between compressive strength and the water-cementitious material ratio shall be determined based on tests. The standard age of the test shall be 28 days.

(b) The water-cementitious material ratio (W/[C+Sg]) to be used for the determination of mix proportions shall be a reciprocal number of the cementitious material-water ratio ([C+Sg]/W), which is obtained as a corresponding value to the mix proportioning strength (f'cr) on the relationship line between cementitious material-water ratio ([C+Sg]/W) and compressive strength (f'c) at the designated age. This f'cr shall be a value which is obtained by multiplying the characteristic compressive strength of concrete (f'ck) with a proper overdesign factor.

It is noted that this factor shall be so determined that the probability of values of strength tests falling below the characteristic compressive strength of concrete shall not exceed 5%, according to the coefficient of the variation of compressive strength expected at each construction site. The factor shall be obtained from the curve shown in Figure 4.3.1.

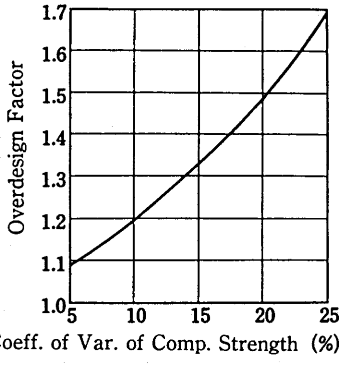


Fig.4.3.1 Overdesign factor for general use

(2) In the case of determining the water-cementitious material ratio based on the freeze-thaw resistance of concrete, the water-cementitious material ratio shall not exceed those shown in Table 4.3.1.

(3) In the case of determining the water-cementitious material 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 0.2% or more sulfate, the water-cementitious material ratio shall not exceed those shown in (a) of Table 4.3.2.

(b) For concrete where a deicing agent is expected to be used, the water-cementitious material ratio shall not exceed those shown in (b) of Table 4.3.2.

(c) For marine concrete structures, the maximum water-cementitious material ratios determined on the basis of the durability of the structure shall follow the values given in Table 4.3.2 as a standard. In case of non-reinforced concrete structures, the values can be increased by about 10%.

Table 4.3.1 Maximum water-cementitious material ratio(%) of air-entrained concrete using ground slag as an admixture when freeze-thaw resistance is to be considered

Exposure condition of structure	Severe weathering or frequent cycles of freezing and thawing		Moderate weathering or infrequent freezing	
	Cross section			
	Thin[2]	Ordinary	Thin[2]	Ordinary
(1)Portions continuously or frequently saturated with water[1]	55%	60%	55%	65%
(2)Portions exposed to ordinary conditions other than (1)	60%	65%	60%	70%

Note 1): Waterways, water tanks, bridge piers, retaining walls, tunnel linings etc., which are frequently saturated with water. Also such portions as girders and deck slabs which are located at a distance from water surface but can be often saturated with water due to melting of snow, water flow, water splash, etc..

Note 2): Portions of structure whose cross sectional thickness is not more than about 20cm.

Table 4.3.2 Maximum water-cementitious material ratio(%) for air-entrained marine concrete using ground slag as an admixture

Environmental Condition	For general construction	For concrete products, or for cases where equivalent conditions of construction and material selection to those of concrete products are guaranteed
(a) Under sea water	50%	50%
(b) Over sea water	45%	50%
(c) In splashing zone	45%	45%

Note: The above figures may be increased by 5% to 10% when confirmed by past experience or research study.

(4)In the case of determining the water-cementitious material ratio based on water-tightness, the water-cementitious material ratio shall be not more than 55%.

[Commentary on 4.3]

Commentary on (1)(a) Although the compressive strength of concrete containing ground slag increases considerably after the age of 28 days, the compressive strength at the age of 28 days shall be the standard strength for concrete containing ground slag as in the case of ordinary concrete. Since the compressive strength of concrete containing ground slag with a constant replacement ratio is linearly related to the cementitious material-water ratio, a principle was set where the water-cementitious material ratio is determined based on the relationship between the compressive strength and the cementitious material-water ratio (C + Sg)/W of the concrete with a constant replacement ratio. For the method to obtain the relationship between (C + Sg)/W and f'c, refer to the commentary on 4.3 of the "Standard Specifications for Design and Construction of Concrete Structures, (Part 2: Construction)".

Commentary one (1)(b) The coefficient of variation of the compressive strength of concrete containing ground slag can be considered to be almost the same as that of ordinary concrete not containing ground slag.

Commentary one (2),(3) and (4) Many experiments have verified that the resistance against freezing, water-tightness, and the durability against chemical reactions due to sea water or chemicals of concrete containing ground slag are the same or better than those of concrete not containing ground slag, if the concrete is thoroughly cured, and that the water-cementitious material ratio of concrete containing ground slag is the same as the water-cement ratio of concrete not containing it (Refer to Chapter 2). This is because concrete containing ground slag has a fine structure and the amount of free calcium hydroxide is reduced by substitution with ground slag. AS it is expected that thoroughly durable concrete will be obtained by applying the water-cement ratio of ordinary concrete not containing ground slag, it is required in these Recommendation that the water-cementitious material ratio, which can be determined by durability, water-tightness, etc. be determined in conformity with the values specified in Items 4.3, 18.2, and 20.3 of the "Standard Specifications for Design and Construction of Concrete Structures, (Part2: Construction Edition)".

4.4 Unit Water Content

Unit water content shall be determined by tests so as to be the least minimum needed permitted by work conditions.

[Commentary on 4.4]

Commentary Table 4.4.1 shows the approximate standard values for the unit water amount required to obtain the predetermined slump. When the slump is the same, the unit water amount of concrete containing ground slag will be smaller by 2 to 5%, differing with the replacement ratio and the fineness of ground slag, than concrete not containing it. The unit water amount required to obtain the same slump will also be increased or decreased by 2 to 3% at each 10°C increment or decrement of the mixing temperature of concrete.

It is possible to substantially reduce the unit water content by appropriately using air entraining agents, water-reducing agents, air-entraining water-reducing agents, or high-performance water-reducing agents. Although the water reduction rate differs with the air content, the quality of ground slag, the type of admixtures, and the mix proportion of concrete, the standard water reduction rates when an agent complying with the provisions of JIS A 6204 "Chemical Admixing Agents for Concrete" is used are : 6 to 10% by air-entraining agents; 10 to 16% by normal or retarding type air-entraining water-reducing agents ; 8 to 14% by accelerating type agents ; and 12 to 20% by high-performance water-reducing agents.

When crushed sand contains a considerably large amount of fine particles, the s/a percentage shall be decreased by 1 to 2%. the basis for determining whether this provision shall be applied or not is the amount of fine particles passing through a 0.15 mm sieve which affects the blending of concrete.

Commentary Table 4.4.1 Approximate values of the unit coarse aggregate volume, the fine aggregate ratio, and the unit water amount of concrete

Max. size of aggr. (mm)	Unit bulk volume of coarse aggr. (%)	Air-entrained concrete				
		Air (%)	With the use of a quality AE agent		With the use of an appropriate amount of a quality 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	45	165	46	155
20	63	6.0	41	160	42	150
25	68	5.0	36	150	37	140
40	73	4.5	32	140	33	130
50	76	4.0	29	131	30	121
80	82	3.5	27	117	28	107

Note(1): The values given in the table above are applied to concrete which contains normal grade sand (fineness modulus, approximately 2.80) and gravel, and of which the water-cementitious material ratio is 0.55 ; the replacement ratio, 50% ; the fineness, 4,000 cm^2/g ; and the slump, 8cm.

Note(2): When concrete with different characteristics from those explained in (1) above or containing different materials is to be used, the values in the table above shall be adjusted according to the table below :

Item	Correction of s/a (%)	Correction of W (kg)
Each 10% increment (decrement) of the replacement ratio of slag powder	Correction unnecessary	Decrease (increase) by 1.5 kg
Each 0.1 increment(decrement) of the fineness modulus of sand	Increase (decrease) by 0.5%	Correction unnecessary
Each 1 cm increment(decrement) of slump	Correction unnecessary	Increase (decrease) by 1.2%
Each 1% increment (decrement) of air content	Decrease (increase) by 0.5 to 1%	Decrease (increase) by by 3%
Each 0.05% increment (decrement) of the water-cementitious material ratio	increase (decrease) by 1%	Correction unnecessary
Each 1% increment (decrement) of s/a	-	Increase (decrease) by 1.5 kg
When crushed gravel is used	Increase by 3 to 5%	Increase by 9 to 15 kg
When crushed sand is used	Increase by 2 to 3%	Increase by 6 to 9 kg

Note: The unit coarse aggregate volume shall be increased (decreased) by 1% for each 0.1 increment (decrement) of the fineness modulus of sand.

4.5 Unit Cementitious Material Content

Unit cementitious material content shall be determined from the unit water content, water-cementitious material ratio and replacement ratio.

[Commentary one 4.5]

This requirement stipulates that the unit cementitious material content, i.e., the unit cement content and the unit ground slag content, be determined by three elements: i) the unit water content; ii) the water-cementitious material ratio, which should be determined in such a manner that concrete with the required strength, durability, and water-tightness is obtained; and iii) the replacement ratio.

4.6 Sand-Aggregate Ratio

The sand-aggregate ratio shall be determined by tests so that the unit water content is minimum while adequate workability is obtained.

[Commentary on 4.6]

Because of the volume of concrete paste is larger and the fineness of concrete is high when ground slag is used, it is possible to reduce the percentage of fine aggregate in concrete containing ground slag as compared with concrete not containing it. The reduction rate varies with the replacement ratio and the fineness of the ground slag. For example, the fine aggregate can be reduced by approximately 0.5 to 1.5% at the replacement ratio of 50% and the fineness of between 3,500 and 4,500 cm^2/g.

With these points taken into consideration, the values in Commentary Table 4.4.1, i.e., the values for the percentage of fine aggregate and the bulk volume of aggregate (unit coarse aggregate volume) were corrected based on the values given in Commentary Table 4.8.1 of the "Standard Specifications for Design and Construction of Concrete Structures (Part2: Construction)".

4.7 Unit Content of Admixture

(1) The unit content of the air-entraining agent and air-entraining and water-reducing agent shall be determined by tests so as to obtain the required air content.

(2) The unit content of admixtures other than those stated in (1) shall be determined based on test data or past experience, so that the needed effects can be obtained.

[Commentary on 4.7]

Commentary on (1) The amount of air-entraining agent (the air-entraining agent only when an air-entraining water-reducing agent is used) required for concrete containing ground slag to obtain the necessary air content tends to be larger than that required by concrete not containing ground slag. The larger the replacement ratio and the finer the ground slag, the more obvious is this tendency. The unit amount of air-entraining agent required for use with ground slag containing gypsum is almost the same as or slightly higher than that required by ground slag not containing gypsum.

The percentage of the amount of water-reducing agent or air-entraining water-reducing agent to the total cementitious material amount should be the same as that of the amount of cement to the amount of ordinary concrete not containing ground slag. In this case, the water reducing ratio will be almost the same or somewhat higher. Regardless of whether or not water-reducing agents, air-entraining water-reducing agents, or high-performance water-reducing agents are used, the higher the replacement ratio of ground slag, the longer the setting of concrete tends to be delayed. It is, therefore, not recommended to substantially increase the amount of such agents to be added.

It is correct to assume that there are less changes in the slump and the air content with the lapse of time owing to the addition of ground slag.

Commentary on (2) Since the effects of admixtures not specified in (1) will differ with the replacement ratio and the fineness of ground slag, this provision requires that the amount to be used be determined based on the results of tests, either previous or conducted exclusively, according to the mix proportion of the concrete, construction conditions, environmental conditions, and the purpose of use. The effects of the fluidization agent should be considered to be the same as those on concrete not containing ground slag.

4.8 Form for Expressing Mix Proportions

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

(2) In the specified mixes, fine aggregate shall be defined as that entirely passing through a 5mm sieve and coarse aggregate retained as a whole on a 5mm sieve. Both aggregates shall be in a saturated surface-dry state.

(3) When converting specified mixes into field mixed, the following points shall be taken into account: the moisture content of aggregates, the quantity of fine aggregate retained on the 5mm sieve, the quantity of coarse aggregate passing through the 5mm sieve, and so on.

Table 4.8.1 Form for expressing mix proportions

Max. size of coarse aggr. (mm)	Range of slump (cm)	Range of air cont. (%)	Water-cem.mat. ratio W/(C+Sg) (%)	Repl. ratio Sg/(C+Sg) (%)	Sand aggr. ratio s/a (%)	Unit content (kg/m^3)							
						Water	Cem.mat.		Fine aggr	Coarse aggr		Admixture	
						W	C	Sg	S	mm-mm	mm-mm	Mine.	Chemi.

Note: The amount of chemical admixture shall be indicated on the basis of its original form before its dilution or dissolution in the unit of cc/m^3 or g/m^3.

[Commentary on 4.8]

Commentary on (1) Table 4.8.1 was formulated to clearly indicate the replacement ratio and the unit amount of ground slag based on the "Standard Specifications for Design and Construction of Concrete Structures (Part 2: Construction)".

CHAPTER 5 CONCRETE PRODUCTION AND PLACING

5.1 General

(1) To produce concrete containing ground slag as an admixture, care shall be taken for batching correctly the ground slag with required quality and mixing the concrete thoroughly to a uniform mix.

(2) To transport and place concrete containing ground slag as an admixture, plans shall be made in advance considering the quality of the concrete.

[Commentary on 5.1]

Commentary on (1) In order to produce concrete containing ground slag which has the required quality, it is important to be aware that ground slag is a part of the cementitious material and that it is a more sensitive material than cement. It is a matter of course, therefore, to use a ground slag with the required quality, but it is also necessary to correctly weigh the material and to thoroughly mix it with concrete in a suitable mixer so that the ground slag can be uniformly dispersed in the concrete.

Commentary on (2) In making a transportation or placement plan for concrete containing ground slag, it is important to consider that the setting of concrete will be delayed when the replacement ratio of ground slag is large and that low temperature at the time of placement will affect not only the short-term but also the long-term development of strength.

5.2 Storage of Ground Slag

Ground slag shall be stored in a moisture-proof container and care shall be taken not to mix the ground slag with other material.

[Commentary on 5.2]

Ground slag solidifies as it absorbs the moisture present in the atmosphere. It is, therefore, important to prevent the ground slag from being exposed to moisture and drafts when stored.

Essentially, ground slag should be stored in an exclusive-use facility, such as silo or storehouse. If ground slag must be stored in the same facility where cement or fly ash was stored, it is necessary to confirm that no previously stored materials remain and that the storage area has been cleaned so that the ground slag will not be mixed with cement or fly ash.

As there are variations in the fineness and the quality of ground slag, e.g., some ground slags contain gypsum, it is necessary to store the materials by the types as is been done for cement or fly ash, except in cases where the ground slags are confirmed to be the same quality by the manufacturer's test certificates.

5.3 Batching of Ground Slag

(1) The batching equipment for ground slag shall be capable of weighing the required quantity correctly and, in principle, shall be an exclusive equipment.

(2) The ground slag shall be batched for each batch by weight.

(3) Batching errors for ground slag shall not be greater than 2% per batch.

[Commentary on 5.3]

Accurate batching of materials is one of the important factors when producing concrete containing ground slag. Since ground slag is a part of the cementitious material and greatly affects the quality of concrete, errors in weighing the materials will result not only in failure to attain the required quality of concrete but also may make the concrete structure to be built with the concrete unsatisfactory. This provision, therefore, in principle requires the use of exclusive equipment for weighing ground slag.

When the equipment used for weighing cement is used for weighing ground slag, it is necessary to inspect it in advance to confirm that no cement remains in the equipment so that the ground slag will not be contaminated with cement. When ground slag and cement are to be weighed separately, it is necessary to confirm whether the weighing accuracy is within the predetermined range of error because the weighing range will be approximately between 30 and 70% of the range normally used.

Commentary on (2) Ground slag must be weighed for each batch like other concrete materials.

Commentary on (3) This provision specifies that the weighing error for ground slag should be the same as that for cement, considering that ground slag is used within the range of 30 to 70% of the total unit amount of cementitious material and that the material is dealt with as a binder similar to cement due to its latent hydraulic properties.

When the equipment used for weighing cement is used for weighing blast furnace slag powder and, in addition, when ground slag and cement are weighed cumulatively, the one with the lighter weight should be weighed first. The weighing error in such instances must be within 0.7% of the material weighed first and the total binder weight, also, in order to guarantee, in this case only, that the weighing error of the material weighed later will be within 2%. If it is not certain whether the weighing error will be within 0.7% or not, it is not recommended to cumulatively weigh materials.

5.4 Mixing

(1) The proper order of charging materials into mixer shall be decided in advance.

(2) The mixing time shall, in principle, be determined by tests.

[Commentary on 5.4]

Commentary on (1) In order to obtain concrete containing ground slag with the required quality, it is necessary to uniformly disperse the ground slag in the concrete. In general, it is recommended to charge ground slag together with or following cement into a mixer.

Commentary on (2) In order to obtain concrete containing ground slag with the required quality, it is necessary to allow a sufficient period of time for mixing to ensure that the ground slag is uniformly dispersed in the concrete. In the case of a batch mixer, the time required to sufficiently mix the materials differs with the type and capacity of mixer, the mix proportion, the type of admixtures, and the order in which the materials are charged. Moreover, there are only a few cases in Japan where ground slag has been used as an admixture. With these points taken into consideration, it is recommended that the mixing time be determined not only in accordance with the provisions of JIS A 1119 (Methods of Test for Variability of Constituents in Freshly Mixed Concrete) but also with the slump and the strength distribution of the concrete.

According to the results of tests carried out in Japan and other countries for mixing concrete by charging cement and ground slag together into a mixer, the dispersibility of ground slag when it is mixed is favorable, and the uniformity of concrete containing ground slag is almost the same as concrete containing portland blast-furnace slag cement. The results also verify that mixing concrete containing ground slag for the same amount of time required for ordinary concrete will cause no problems if the materials are mixed in a fully equipped plant. When mixing tests will not be carried out, the mixing time may be standardly set at one minute and thirty seconds for tilting mixers and one minute for forced batch mixers, provided that the materials are mixed in a fully equipped plant.

5.5 Transportation and Placing

(1) Concrete shall be transported quickly, placed immediately and compacted fully. The time from the start of mixing and to the completion of the placing shall, in principle, not exceed one and a half hours when the outdoor temperature is above 25°C, and two hours when it is 25°C or below but not less than 10°C.

(2) The temperature of the atmosphere during placing concrete shall be, in principle, not less than 10°C.

[Commentary on 5.5]

Commentary on (1) Concrete containing ground slag can be transported and placed in the same manner as ordinary concrete. It is desirable, however, to draw up a plan and execute construction with the following points in mind: when the replacement ratio of ground slag is high, the setting of concrete is generally delayed and the reduction in slump with the lapse of time tends to be small compared to ordinary concrete; and with the use of superplasticizer, however, the setting of concrete will be accelerated.

Commentary on (2) When the temperature of concrete at the time of placement is low and if the temperature of concrete while curing cannot be maintained at more than 10°C, it is difficult for concrete containing ground slag to reach the required strength, not only in early stages but also over the long-term. Care shall be exercised especially when placing concrete for slabs, walls, and other members with a thin wall thickness, since the temperature of concrete will not be raised even by the heat of hydration generated by hardening if the temperature of concrete at the time of placement is low. In the case of mass concrete, however, as the temperature of concrete will rise due to the heat of hydration generated by hardening, the minimum allowed temperature for placing may be lowered to 7°C provided that the concrete will be thoroughly cured.

CHAPTER 6 CURING OF CONCRETE

6.1 General

After placing the concrete containing ground slag, the concrete shall be cured while maintaining the necessary temperature and humidity conditions for the hardening and also to prevent the influence of harmful effects.

[Commentary on 6.1]

Moist curing, particularly in initial stages, has a greater influence on the quality of concrete containing ground slag than on ordinary concrete. It is therefore important to exercise thorough consideration when curing the concrete. The development of the strength of concrete is greatly affected by the temperature of concrete at the time of placement as well as the temperature during curing. As the development of strength will be inferior at low temperatures in particular, it is necessary to keep the temperature of concrete while curing at least the same as when it is placed, especially in the case of slabs, walls, or other members with small dimensions. Drying in early stages also has a great influence on the quality of concrete. Insufficient maintenance of moist conditions will not only result in inferior development of strength but also may result in extremely low durability even if the long-term strength is satisfactory.

6.2 Moist Curing

(1) Throughout the curing period, the exposed surfaces of placed concrete shall be kept wet and the loss of moisture due to the exposure to sunshine and wind shall be prevented.

(2) When the concrete has hardened enough to allow jobs being performed without damaging the surface, the exposed surface of the concrete shall be kept wet by covering it with a moist curing mat, cloth, or other materials or by sprinkling or filling the area with water.

[Commentary on 6.2]

<u>Commentary on (1)</u> It is desirable to provide a sun shield or a wind shield with sheets, etc. on the surfaces of concrete, including those facing the forms, to prevent moisture from leaving the concrete.

<u>Commentary on (2)</u> When the forms for walls, beams, and columns are removed during curing, the exposed concrete surfaces must be kept wet. When membrane curing is to be conducted, the effects should be confirmed in advance.

6.3 Period for Moist Curing

The period for moist curing the concrete containing ground slag shall be, in principle, determined by tests. When ordinary portland cement is used in the concrete, the values given in Table 6.1 may be used as a standard curing period.

Table 6.1 Period for moist curing

Average temp. of atmosphere during curing	Replacement ratio		
	30% - 40%	40% - 55%	55% - 70%
17°C or above	not less than 5 days	not less than 6 days	not less than 7 days
10°C or above less than 17°C	not less than 7 days	not less than 8 days	not less than 9 days
5°C or above less than 10°C	not less than 9 days	not less than 10 days	not less than 11 days

[Commentary on 6.3]

Keeping concrete wet as long as possible is generally effective to increase its strength. The early stages of curing are especially important for concrete containing ground slag and such concrete should be kept wet for a longer period of time than concrete containing ordinary portland cement. Table 6.1 shows the typical periods for moist curing. It is desirable, however, to determine the moist curing period taking into consideration various factors such as the type of ground slag and the cement to be used, the type of structure, position, weather conditions to which the concrete will be exposed, construction period, and construction methods. Even if the temperature is quite high, it is desirable to keep concrete wet for at least five days. When high-early-strength portland cement is used with the aim of making the moist curing period shorter than specified in the table above, it is necessary to make a thorough investigation including an examination of the compressive strength using a specimen taken from concrete cured under the same conditions to which the actual structure will be subjected .

To determine the time required for concrete to attain the sufficient strength to enable the forms for slabs, beams, etc. to be removed, it is recommended to use as a criteria for judgement the compressive strength of a specimen taken from concrete in the same manner as mentioned above.

6.4 Curing Temperature

During the curing period, concrete temperature shall be kept, in principle, at 10°C or above.

[Commentary on 6.4]

Placing concrete in winter or under low temperatures will interfere with the hydration reaction of cement and ground slag, resulting in delayed development of strength or frost damage in early stages. It is therefore desirable to keep the temperature of concrete at least at 10°C while curing by providing insulation or supplying heat. Care should be exercised especially when the wall thickness is thin and the temperature of concrete should be kept at least at 7°C even when placing mass concrete.

When the temperature is extremely high, when a large fluctuation in temperature is expected, or when the member has large dimensions and a considerable rise in temperature is expected, cracks may occur due to thermal stresses. In such cases, it is necessary to control the temperature of concrete or temperature variation by methods such as pipe cooling, insulation of surfaces, or a combination of these.

When concrete is cured while the temperature is being controlled, it is necessary to adopt adequate temperature control methods and to properly set the curing period taking into consideration the type of concrete as well as the shape and dimensions of the structure so that the concrete will not be adversely affected by sudden changes in temperature.

6.5 Accelerated Curing

For accelerated curing such as steam curing, the starting time of curing, speed of heating, speed of cooling, curing temperature, curing hours and so on, shall be so determined as to prevent adverse effects on the concrete.

[Commentary on 6.5]

When steam curing or any other type of accelerated curing is to be carried out to accelerate the hardening of concrete, it is necessary to properly set the starting time of curing, temperature rise speed, curing temperature, curing period, etc. by referring to past data so that the concrete will not be adversely affected. If concrete containing ground slag is used, it is necessary to pay particularly close attention to the starting time of curing and the maintenance of moist conditions.

CHAPTER 7 READY-MIXED CONCRETE

7.1 General

As a rule, in the case of using ready-mixed concrete, ready-mixed concrete conforming to JIS A5308 shall be used.

[Commentary on 7.1]

When ground slag is used as an admixture with ready-mixed concrete,the ready-mixed concrete is classified as a specially ordered product categorized in JIS A5308 "Ready-mixed Concrete". This chapter describes the matters to be noted in addition to the provisions of JIS A 5308 when concrete containing ground slag is produced in batching plants.

7.2 Choice of Concrete Plants

(1) In principle, the supplier's plant of ready-mixed concrete shall be chosen from among the plants which are not only JIS-mark licensed but also operated or controlled by persons who are authorized by JCI as Chief Concrete Engineer or Concrete Engineer with enough experience.

(2) In choosing concrete plant, the following matters shall be taken in account: storage facility for ground slag, batching equipment and recording printing machine of batched ground slag, condition of quality control of ground slag, transporting time to sites, unloading time, manufacturing equipment and capacity, number of transporting cars, and so on.

[Commentary on 7.2]

Ground slag is dealt with as a binder with an excellent quality equivalent to cement. The batching plant selected should satisfy the following requirements: the plant should have a storage facility where ground slag can be stored in the same conditions as cement is stored as well as weighing equipment with which ground slag can be weighed with the same accuracy as cement is weighed; and in addition, complete quality control should be assured. It is also desirable from the viewpoint of assuring the reliance of the purchaser on the manufacturer to select a batching plant with a special recording printing machine which prints out the replacement ratio or the amounts of all materials used in each batch so that the amount of ground slag used can be confirmed.

The process of using ground slag as an admixture is relatively new and has not yet become popular in Japan. In order to assure the highest possible reliability, it is recommended that a batching plant be selected only if it satisfies the provisions hereof regarding weighing, mixing, and transportation, that it has been permitted to bear the JIS mark, and if it employs full-time, experienced concrete engineers.

7.3 Designation on Quality

In designating ready-mixed concrete using ground slag as an admixture, the purchaser shall specify both the nominal strength and the slump of concrete.

The purchaser shall specify the following requirements for concrete after discussion with relevant suppliers:

(a) quality of ground slag,
(b) replacement ratio of ground slag,
(c) type of cement,
(d) type of aggregate,
(e) maximum size of coarse aggregate,
(f) age of concrete guaranteeing nominal compressive strength,
(g) type of admixture,
(h) air content,
(i) maximum and minimum temperatures of concrete,
(j) other necessary items, if necessary.

[Commentary on 7.3]

In designating the quality of ground slag, the characteristics of the material must be thoroughly understood in advance by conducting quality examinations or tests. Since the strength of concrete at a given age differs with the replacement ratio, the type of cement used, admixture, temperature etc., a purchase order should be placed only after it has been confirmed that all the requirements as to strength, calorific value, etc. are satisfied.

The designation for the water-cementitious material ratio and the unit cement amount is covered, by item (j), "other necessary items".

7.4 Acceptance of Supplied Concrete

(1) The acceptance of supplied concrete shall be done in accordance with items (1) to (4) of Section 6.4 "Acceptance of Supplied Concrete" of the JSCE "Standard Specification for Design and Construction of Concrete Structures (Part2: Construction)"

(2) Acceptance inspections of concrete for strength, slump and air content shall be performed in accordance with JIS A5308.

When required by the purchaser, the supplier of the concrete shall present the recorded figures of either replacement ratio or charged amount of ground slag per each batch.

[Commentary on 7.4]

(1) The preparation for receiving ready-mixed concrete, communication with the manufacturer, the unloading place of ready-mixed concrete, and other matters to be noted shall be in accordance with the provisions of the "Standard Specification for Design and Construction of Concrete Structures".

(2) The replacement ratio of ground slag shall be checked with the figures of the replacement ratio or the mixed amount of ground slag per batch indicated by a printing machine. If necessary, the purchaser may be informed of the replacement ratio obtained after the test conducted as per the "Test method for replacement ratio of ground slag".

CHAPTER 8 QUALITY CONTROL AND INSPECTION

8.1 General

Concrete materials, reinforcing steel, machinery, equipment, and the workmanship shall be controlled in order to economically construct concrete structures with the required quality.

[Commentary on 8.1]

The characteristics of concrete containing ground slag vary not only with the quality of the ground slag but also with the quality of other materials used with it, the replacement ratio, and curing conditions. It is therefore important to provide adequate control considering the purpose of use so that the required quality and performance can be assured.

8.2 Tests

8.2.1 Test Methods

Test methods, as a rule, shall be in compliance with the methods specified by JIS.

8.2.2 Tests for Concrete

(1) Preliminary tests on the required concrete material and other necessary tests for determining the mix proportions of concrete shall be performed prior to the work. There shall also be inspections to check the performance of machinery and equipment.

(2) The following tests shall also be performed as the circumstances require during construction:

(a) aggregate test,
(b) slump test,
(c) air content test,
(d) replacement ratio tests of ground slag,
(e) bulk density test of concrete,
(f) compressive strength test of concrete,
(g) chloride content test of concrete,
(h) other tests required.

(3) The concrete test specimens cured under conditions as close to the field conditions as possible, shall be tested for strength to estimate the adequacy of curing, appropriate time for form removal and prestressing or to ensure safety in case a load is to be applied to the structure at an early stage.

[Commentary on 8.2.1]

In addition to the test methods stipulated in JIS, the standards of JSCE shall also apply. As to the testing methods for the replacement ratio of ground slag, the JSCE standard, "Test Method for Replacement Ratio of Ground Slag Used as an Admixture (Draft)", is applicable.

[Commentary on 8.2.2]

Commentary on (2) In order to confirm whether concrete containing ground slag has the quality required to construct the concrete structure concerned, it is necessary to test the concrete as well as its constituent materials while the work is under way.

Commentary on (d) The quality of concrete containing ground slag varies with the replacement ratio. In order to construct a concrete structure satisfying the predetermined requirements, it is important to check whether the concrete produced has the required replacement ratio or not.

The test for the replacement ratio of ground slag shall be in accordance with the JSCE standard "Test Method for Replacement Ratio of Ground Slag Used as an Admixture (Draft)". This method is the salicylic acid acetone dissolution method which takes advantage of the characteristics of admixture where cement clinker and the hydrates of binders dissolve in salicylic acid but vitreous un-hydrated ground slag does not dissolve.

Commentary on (g) To check the chloride content in fresh concrete, the following methods are available: 1) those conforming to the JSCE standard, "Testing Methods for the Content of Chloride in Sea Sand (Draft); 2)potentiometric titration; 3) the ion chromatographic method; 4)the test paper method; and 5)the ion electrode method, the last two of which are suitable for tests conducted at the work site. Attachment 5 of JIS A 5308 "Ready-mixed Concrete" stipulates the "Testing method for the concentration of chlorine ions of the water in the concrete not yet hardened".

Since the sulfide in concrete containing ground slag acts as an interfering ion, some tests for checking the chloride content may require the oxidation of the sulfide before the tests are executed. In carrying out the tests to check the chloride content, therefore, it is suggested to select the most appropriate of the reliable methods taking the principle, accuracy, characteristics, etc. of each method into consideration, and to consistently use the same method.

Commentary on (3) Concrete containing ground slag is more greatly affected by the curing temperature and the moist conditions during curing than ordinary concrete. Test specimens in particular are easily affected by low temperatures and drying conditions and it is impossible to obtain identical curing conditions only by placing test specimens at the same position where the concrete structure concerned will be located. It is therefore necessary to consider the temperature and humidity so that specimens will be cured under the same conditions as the concrete structure concerned.

8.3 Quality Control of Concrete Based on Water-Cementitious Material Ratio

(1) Quality control of concrete based on water-cementitious material ratio shall be done by the water-cementitious material ratio obtained from

analyzing fresh concrete.
(2) The water-cementitious material ratio obtained by tests for quality control of concrete shall be the average of water-cementitious material ratios obtained from the two samples taken from the same batch.

[Commentary on 8.3]

Obtaining the water-cementitious material ratio by analyzing fresh concrete is the quickest of all methods to understand the quality of concrete. When the water-cementitious material ratio is determined based on the durability of concrete or on the compressive strength of concrete, it is possible to control concrete by estimating the compressive strength of concrete at the age of 28 days from the relationship between the water-cementitious material ratio and the compressive strength obtained in advance, provided, however, that there are no changes in the materials used and the variation of the slump is within the normal range.

The water-cementitious material ratio of fresh concrete can be measured and tested by applying the conventional methods for testing the water-cement ratio of fresh concrete.

CHAPTER 9 GENERAL CONSIDERATIONS FOR STRUCTURAL DESIGN

9.1 General

In designing concrete structures containing ground slag, sufficient consideration shall be made on such as quality of ground slag to be used, mix proportion of concrete, and construction conditions.

[Commentary on 9.1]

As the properties of concrete containing ground slag change with the quality of the ground slag used, the mix proportion of concrete, construction conditions, etc., it is necessary to take these points into consideration when designing concrete structures.

For matters not specified in this chapter, the "Standard Specification for Design and Construction of Concrete Structures (Part1: Design)" shall apply.

9.2 Unit Weight of Concrete

The unit weight of reinforced concrete, non-reinforced concrete, and mortar containing ground slag may be taken as 2,450 kg/m^3, from 2,300 kg/m^3 to 2,350 kg/m^3, 2,150 kg/m^3, respectively.

[Commentary on 9.2]

The specific gravity of ground slag is somewhat smaller than that of portland cement. Since the difference is small and little affects the entire weight of concrete, the values specified in the "Standard Specification for Design and Construction of Concrete Structures" apply to the unit weight of concrete.

9.3 Modulus of Elasticity

As a rule, modulus of elasticity for concrete to be used either for calculation of elastic deformation or statically indeterminate force shall be, in principle, an average of tested values for secant elastic modulus at one third point of compressive strength which is calculated from the stress-strain curve obtained by the compressive test in accordance with JIS A1108 "Test Method for Compressive Strength of Concrete".

The modulus of elasticity (E_c) given in Table 9.1 may generally be used when the compressive tests are not performed. However, in the case of designing a structure using allowable stress theory, the elastic modulus of concrete shall be kept to 1.4×10^5 kgf/cm^2 when determining cross section or calculating stresses.

Table 9.1 Elastic modulus of concrete

$f'ck$ (kgf/cm^2)		180	240	300	400	500	600
Elastic Modulus Ec (x 10^5 kgf/cm^2)	ordinary concrete	2.2	2.5	2.8	3.1	3.3	3.5
	lightweight aggr.concrete	1.3	1.5	1.6	1.9	-	-

[Commentary on 9.3]

Since there is no marked difference in the elastic modulus for concrete containing ground slag and concrete not containing it, the values specified in the "Standard Specification for Design and Construction of Concrete Structures" apply. Not much data on concrete using light-weight aggregate is available. However, as the elastic modulus of such concrete shows a tendency similar to that of ordinary concrete, the values specified in the "Standard Specifications for Design and Construction of Concrete Structures" may be applied too.

9.4 Drying Shrinkage

Drying shrinkage of concrete shall be determined, in principle, considering humidity around structures, shape and dimension of members, mix proportion of concrete, and curing conditions.

[Commentary on 9.4]

According to the results of previous experiments, the long-term dry shrinkage of concrete containing ordinary portland cement and ground slag is nearly the same or less than that of concrete not containing ground slag if the concrete is thoroughly cured. No distinguishing difference however has been observed. Therefore, the values specified in the "Standard Specifications for the Design and Construction of Concrete

Commentary Table 9-1 Dry shrinkage strain of concrete (x 10^{-6})

Age of concrete / Environmental conditions	4 ~ 7 days	28 days	3 months	1 year	Conditions
Outdoors	200	180	160	120	Effective height: Approx. 20 ~ 60 Slump: 5 ~ 10cm Humidity Outdoors: 70% Indoors : 40%
Indoors	350	270	210	120	

Structures" can be applied in calculations when ordinary portland cement is used and the values given in Commentary Tables 9.1 and 9.2 may generally be used. The values for less than age of 3 days specified in the "Standard Specification for Design and Construction of Concrete Structures", however, should not be applied for concrete containing ground slag because the dry shrinkage is relatively large at early ages and such concrete must be cured for at least five days.

Commentary Table 9-2 Dry shrinkage strain obtained when redundant force is calculated based on the elasticity theory

	Dry shrinkage strain	Remarks
When redundant force is calculated based on the elasticity theory	150×10^{-6}	The effects of creep need not be taken into consideration.

9.5 Creep

(1) Creep strain of concrete may be obtained generally by equation (9.1), assuming that it is proportional so the elastic strain caused by an applied stress.

$$\sigma'cc = \varphi \cdot \sigma'cp/Ec \quad \cdots\cdots (9.1)$$

where, φ : creep factor
$\sigma'cp$: compressive stress in concrete produced by permanent loads
Ec : modulus of elasticity

(2) As a rule, creep factors of concrete shall be determined, with considerations to factors such as humidity around structure, shape and dimension of cross section of a member, mix proportion of concrete, curing condition, concrete age at stress application.

[Commentary on 9.5]

Commentary on (2) The creep of concrete is affected by various factors such as the properties of the aggregate, the type of cement, compacting, and curing conditions of the concrete in addition to the ambient temperature and humidity of the structure, the dimensions and the shape of members, the mix proportion of concrete, and the age of concrete when loads are applied. The creep coefficient to be used for design should, therefore, be determined based on the results of tests, previous or exclusive, as well as the results of measurements on the actual structure.

When tests are not to be carried out, ordinary portland cement should be used. When concrete containing ground slag is used for prestressed concrete members, the values given in Commentary Table 9.3 may generally be used as the creep coefficient.

Commentary Table 9.3 Creep coefficient of concrete containing ground slag*

	Environmental Conditions	Age of concrete when prestressing or application of loads					Conditions
		4-7 days	14 days	28 days	3 mon.	1 yr.	
When using ground slag with fineness from 3500 to 4000 cm^2/g with a replacement ratio of 40 to 50%	Outdoors	2.9	2.6	2.2	1.9	1.4	Wall thickness: Approx. 60cm Slump: 5~10cm
	Indoors	4.5	3.8	3.1	2.4	1.6	Outdoors (Temperature 15°C, humidity 70%) Indoors (20°C, 40%)

* The values above do not apply to concrete containing light-weight aggregate.

The values for 4 to 7 days and 14 days shown in Commentary Table 9.3 were obtained through calculation based on the concept of the Standard Specification for the Design and Construction of Concrete Structures and assuming that the hardening speed of concrete containing ground slag would be 70% of concrete containing ordinary portland cement (coefficient for the hardening speed of concrete was assumed to be 0.7). The values are, therefore, relatively larger than those for concrete containing only ordinary portland cement. According to the results of previous studies, the creep coefficient of concrete containing ground slag is almost the same as or somewhat smaller than that of ordinary concrete if the concrete has been thoroughly hydrated. It was determined, therefore, that the values specified in the "Standard Specification for Design and Construction of Concrete Structures" for concrete containing ordinary portland cement would only apply to the creep coefficient values for the ages of 28 days or after.

As it is considered that not only the hardening speed but also the difference in the internal structure of the binder affect the creep coefficient of concrete containing ground slag, further studies and actual measurements will be necessary to quantitatively evaluate the creep coefficient. When the effect of creep is considered large in designing concrete structures, it is suggested to conduct tests to determine the creep coefficient.

CHAPTER 10 MASS CONCRETE

10.1 Scope of Application

This chapter provides the general requirements especially needed for mass concrete structures when concrete containing ground slag as an admixture is used.

[Commentary on 10.1]

Since the exothermic speed due to the hydration of concrete containing ground slag at a replacement ratio of 50% or more is slow, it is expected that the effects from the use of ground slag for mass concrete will be large. This chapter describes the characteristics of concrete containing ground slag when it is used as mass concrete as well as the matters to be noted in doing so.

10.2 General

When ground slag is used in mass concrete as an admixture, to obtain adequate quality of concrete structure, construction plan shall be made after thorough examination of thermal stress and thermal cracks caused by heat of hydration of cementitious material and the construction work shall be performed as planned.

[Commentary on 10.2]

Various measures are considered from the design stage and the selection of materials to the construction stage to control the cracks appearing in mass concrete, including the prevention of cracks and the regulation of the location where cracks appear and the crack width. Concrete containing an appropriate amount of ground slag with adequate quality can be used as a measure against thermal cracks as such concrete characteristically makes the exothermic speed slower. A thorough examination should be made, however, as inadequate selection of the quality and the replacement ratio of ground slag, or the type of cement, may otherwise accelerate the heat of hydration. In construction, curing at initial stages is very important. As described in Section 6.3, concrete containing ground slag should be kept moist longer than concrete containing ordinary portland cement.

10.3 Materials and Mix Proportion of Concrete

When determining the materials and mix proportion of mass concrete, the temperature rise of concrete shall be kept to a minimum within a range where the characteristic compressive strength and the required workability can be satisfied.

[Commentary on 10.3]

In order to control the rise in the temperature of concrete, since the heat of hydration of cementitious material is almost proportional to the unit cementitious material content, it is necessary to find an appropriate mix proportion that will keep the unit cementitious material content within the extent which satisfies the required quality. The temperature of the concrete containing ordinary portland cement increases or decreases 1°C for each $10kg/m^3$ of unit cement content. When ground slag with less fineness is used at a large replacement ratio, the exothermic speed tends to be delayed. However, when the replacement ratio is small and the fineness is large, the hydration is promoted and the effect of the concrete in controlling the temperature rise by the radiation of heat will be small. When ground slag is used for mass concrete, it is recommended that the specific surface area be kept within the extent that satisfies the standard values at the replacement ratio of ground slag within 50 to 70%.

It has been verified by experiments that the rise in the adiabatic temperature will be lowered when moderate-heat portland cement is used instead of ordinary portland cement at the same replacement ratio of ground slag.

For some types of concrete structures, it will be advantageous to set the age of concrete for the standard design strength at longer than 28 days, taking advantage of the fact that the long-term development of strength is improved if the heat generation at initial stages is controlled.

10.4 Evaluation of Thermal Cracking

The adiabatic temperature rise of concrete, which is necessary for evaluation of thermal cracking, shall in principle be determined by tests.

[Commentary on 10.4]

The exothermic properties of concrete containing ground slag differ with the temperature of concrete at the time of placement and the curing temperature in addition to the quality of ground slag, the type of cement, the unit cement content, and the replacement ratio. However, since the data presently available for estimating the rise in the adiabatic temperature of concrete is sparse, the rise in the adiabatic temperature should basically be determined by confirming the exothermic properties of concrete by testing.

The rise in the adiabatic temperature of concrete is a basic constant in analyzing the changes in the internal temperature of concrete after placement, and can be expressed by the commentary equation 10.4.1:

$$Q(t) = Q\ \ (1 - e^{-\ t}) \quad \text{........ (Commentary equation 10.4.1)}$$

Where, Q is the constant for the ultimate adiabatic temperature rise, is the constant for the temperature rise speed, both being determined by experiments, t is the age of concrete (days), and Q(t) is the adiabatic temperature rise (°C) at the age of t days.

The results of previous tests show that Q of concrete containing ground slag at a replacement ratio of less than 60% increases by approximately 10% more than that of concrete containing ordinary portland cement. It has been confirmed, however, that Q will decrease considerably when the replacement ratio is over 65%. When ground slag with a fineness between 3000 and 6000 cm^2/g is used, will be less than approximately two third of that of concrete containing only ordinary portland cement.

CHAPTER 11 COLD WEATHER CONCRETING

11.1 Scope of Application

This chapter provides the general requirements especially needed in cold weather concreting when concrete containing ground slag is used.

[Commentary on 11.1]

When concrete containing ground slag is used for cold weather concreting, thorough care should be exercised during construction. This chapter describes the matters to be noted when constructing with such concrete under low temperatures compared with construction using ordinary concrete.

11.2 General

(1) When the mean daily temperature is expected to drop below 4°C, execution of concreting shall be conducted as cold weather concreting.

(2) In cold weather concreting of concrete containing ground slag as an admixture, special care shall be taken in regard to items as concrete materials, mix proportion, mixing, transporting, placing, surface finishing, curing, and formwork and shoring.

[Commentary on 11.2]

As in the case of ordinary concrete, the work using concrete containing ground slag should also be dealt with as cold weather concreting when construction takes place at the average daily temperature of less than 4°C. The setting and hardening of concrete containing ground slag will be considerably delayed at low temperatures as compared to ordinary concrete; therefore, the development of strength at early stages is small, making the concrete susceptible to frost damage. When concrete containing ground slag is used for cold weather concreting, it is important to provide not only insulated curing but also certain measures such as the maintenance of the temperature of concrete at the required level by supplying heat. During curing, it is also necessary to keep the concrete wet and prevent it from drying. For materials of concrete, mix proportion, placing, surface finishing, formwork and shoring, more sufficient measures than those for ordinary concrete should be taken to prevent not only the reduction of concrete temperature but also the evaporation of moisture from concrete.

11.3 Materials

(1) The ground slag to be used shall possess a high activity index so as to obtain high early strength of concrete.

(2) Both cement and ground slag shall never be directly heated for use.

[Commentary on 11.3]

Commentary on (1) It is a matter of course that the ground slag to be used should satisfy the JSCE standards. In addition it is important to use ground slag with a high activity index, a high basicity, and a high fineness. The ground slag to be used shall be with a fineness of more or equal to 4,000 cm^2/g or and, if possible, more than 5,000 cm^2/g is preferable, as ground slag with such a fineness promotes hydration at initial ages, which is advantageous for construction using concrete at low temperatures.

Commentary on (2) Since the heating of ground slag is impossible and in addition, ground slag is used as a replacement of cement, it is determined that the ground slag should not be heated considering the effects to cement, as neither should cement.

11.4 Transporting and Placing

Concrete temperature at the time of placing shall be determined in the range between 7°C and 25°C taking into account the minimum dimension of the structure and environmental conditions.

[Commentary on 11.4]

When the average day temperature is lower than 4°C, the hardening speed of concrete will be considerably delayed and the worse point is that the concrete will freeze when the temperature drops sharply. As quality of concrete containing ground slag is greatly affected by temperature, it is necessary to raise the lowest temperature at the time of the placement of concrete higher than that for concrete containing portland cement only. Care should be exercised, however, as excessively high temperatures at the time of the placement of concrete will accelerate the rise in the heat of hydration. It is generally recommended to keep the temperature of concrete at the time of placement between 7°C and 25°C, which is not so different from the curing temperature. With these points taken into consideration, Commentary Table 11.1 shows the recommended standard values for the temperature of cold weather concreting.

Commentary Table 11.1 Recommended range of concrete temperature at the time of placement

Range of temperature (°C)	Thickness of cross section		
	Thin	Ordinary	Thick
Lowest limit	13	10	7
Utmost limit	25	20	20

11.5 Curing

The curing of concrete exposed to severe weather conditions shall be continued, in principle, until the compressive strength given in Table 11.1 is developed maintaining the temperature of concrete above the lowest limit at the time of placement. Further, the concrete temperature shall be maintained above 0°C for at least 2 days after curing period.

Table 11.1 Standard values for the required compressive strength of concrete at the end of curing under severe weathering conditions (kgf/cm^2)

Exposure condition of structure	Thickness of cross section		
	Thin	Ordinary	Thick
(1) Portions continuously or frequently saturated with water	150	120	100
(2) Portions exposed to ordinary conditions other than (1)	50	50	50

[Commentary on 11.5]

It has been verified that concrete containing ground slag will not receive frost damage even if it is subjected to freezing several times during a winter season after the completion of curing if an appropriate amount of air is entrained in the concrete and the compressive strength reaches 50 kgf/cm^2 or more. It is also said that concrete will deteriorate less, even if it is exposed to severe weather conditions, if the compressive strength exceeds 100kgf/cm^2. Based on these points, the values for the compressive strength shown in Table 11.1 were determined for members with different thicknesses and for different exposure conditions. Even if this level of compressive strength is obtained, it is necessary to cure the concrete for three days at the required temperature and to maintain the concrete for two days thereafter at least at 0°C. It is needless to say that the concrete has to be cured until a sufficient strength against the loads expected during construction are applied.

Since the number of days of curing required to obtain the strength shown in Table 11.1 differs with the activity index of ground slag, the replacement ratio, the unit cementitious material content, the water-cementitious material ratio, and the curing temperature,it should be determined in principle from the compressive strength of a concrete specimen cured under the same condition to which the actual concrete structure is subjected. Commentary Table 11.2 shows the standard number of days required to cure, at 10°C, concrete containing ground slag with a fineness between 3,500 and 4,500 cm^2/g which has been substituted for ordinary portland cement at the rate of 40 to 55%.

Commentary Table 11.2 The standard number of days required to cure, at 10°C, concrete containing ground slag with a fineness between 3,500 and 4,500 cm^2/g, and replaced ordinary portland cement at the rate of 40 to 55%. (Thickness of cross section: ordinary)

Exposed conditions of the portions of structures	Number of days for curing
(1) Those continuously or often saturated with water	9 days
(2) Those in a normal exposure condition and not falling under (1)	4 days

Note: The number of days for curing indicated in the table above show the days during which concrete should be insulated or heat supplied to concrete to prevent frost damage.

CHAPTER 12 HOT WEATHER CONCRETING

12.1 Scope of Application

This chapter provides the general requirements especially needed in hot weather concreting with concrete containing ground slag as an admixture.

[Commentary on 12.1]

This chapter describes the matters to be noted, compared with ordinary concrete, when ground slag is used in hot-weather concreting.

12.2 General

In hot weather concreting of concrete containing ground slag, adequate treatment for materials, mix proportioning, mixing, transporting, placing, and curing. Care shall be taken so that the quality of concrete does not deteriorate due to high temperature.

[Commentary on 12.2]

Concrete containing ground slag is advantageous when it is used for hot-weather concreting because it's slump loss is small, it can be transported for a longer period of time, and cold joints occur less often as compared with concrete containing ordinary portland cement. In order to obtain these effects, it is recommended that the replacement ratio be set within the range of 50 to 70%. In the case of hot-weather concreting, concrete is apt to dry out. This tendency is more obvious when the setting of concrete is delayed. It is therefore necessary to take this point into consideration when constructing with concrete containing ground slag. It is especially important that the concrete is protected from drying out at early ages by providing sufficient moist curing condition.

CHAPTER 13 MARINE CONCRETE

13.1 Scope of Application

This chapter provides the general requirements especially needed in marine concrete structures using concrete containing ground slag as an admixture.

[Commentary on 13.1]

The durability and the quality of concrete containing ground slag to be used in marine environments are considered to be the same or better than those of ordinary concrete. This chapter describes the matters to be noted, compared with ordinary concrete, when ground slag is to be used in marine environments.

13.2 General

When concrete containing ground slag is used in marine concrete structures, replacement ratio of ground slag, mix proportion of concrete, and cover to reinforcements shall be determined so that the structure shall possess required durability in marine environment.

[Commentary on 13.2]

When concrete containing ground slag is used, if the water-cementitious material ratio, the mix proportion, and the cover to reinforcement are the same as those for ordinary marine concrete structures, the sea water resistance of concrete and the ability to protect reinforcing bars from corrosion in marine environments are better than those of ordinary concrete.

In other words, when ground slag is used, the resistance of the concrete to sulfate as well as the protection of reinforcing bars are improved as in the case of portland blast-furnace slag cement. The reasons for the improved ability to protect reinforcing bars of concrete containing ground slag are considered attributable to, similar to portland blast-furnace slag cement type B, improved resistance against the permeation of chlorine ions. Another reason for the improvement is considered to be that oxygen does not easily permeate concrete containing ground slag.

Although concrete containing ground slag has the disadvantage that the neutralization speed is somewhat quicker than that of concrete containing ordinary portland cement, there will generally be no problems as more than 5cm of concrete covering is assured for concrete structures located in marine environments.

In order to obtain concrete with an excellent resistance against sea water, it is desirable to set the replacement ratio of ground slag at least at 40%.

13.3 Concreting Works

When concrete containing ground slag is used in marine concrete structures, concreting works shall be done taking special care for curing of concrete.

[Commentary on 13.3]

Since concrete containing ground slag has different characteristics in the development of strength and the dry shrinkage from those of ordinary concrete, it is necessary to exercise special care in curing, removal of forms, etc. Marine conditions sometimes require early removal of forms. In the case of concrete containing ground slag, however, it is necessary to thoroughly examine the work process so that early removal of forms will not be necessary. When concrete is placed in multiple layers such as for caissons, more thorough care should be exercised in curing the top layer than other layers as the top layer dries easily.

When concrete containing ground slag is produced by concrete plant ships, it is generally necessary to use a storage tank and weighing equipment exclusively used for ground slag. In some cases, however, the pre-mixed material consisting of cement and ground slag may be used.

CHAPTER 14 CONCRETE FOR PAVEMENTS

14.1 Scope of Application

This chapter provides the general requirements especially needed in concrete pavements using concrete containing ground slag as an admixture.

[Commentary on 14.1]

Pavement is subject to severe conditions : it is exposed to weather over the years, and is subject to bending action due to traffic loads as well as repeated stress due to constant changes in temperature. Concrete to be used for pavement is therefore required to have a high bending strength, a small dry shrinkage, a small heat generation when hardening, small abrasion, etc.

The use of ground slag is considered to allow concrete with equal or superior a performance as per requirements to ordinary concrete to be obtained. This chapter describes the matters to be noted when concrete containing ground slag is used for pavement.

As to the matters not specified in this chapter the provisions of the "Standard Specification for the Design and Construction of Concrete Structures (Pavement)" shall apply.

14.2 Replacement Ratio

The determination of replacement ratio of concrete for pavements shall be done so as to meet the required properties of concrete.

[Commentary on 14.2]

Various purposes form the reason for using concrete containing ground slag for pavement. The primary objectives are to control total heat of hydration and to stem alkali-aggregate reaction. In order to attain these objectives, it is recommended to use ground slag in the ranges of 50 to 70%, and 40 to 70%, respectively. Generally, the bending strength at the age of 28 days is used as the standard strength of the concrete used for pavement. To take advantage of ground slag, it is sometimes better to use the strength at the age of longer than 28 days as a standard. In such a case, it is suggested to determine the replacement ratio based on construction conditions, etc.

14.3 Concreting Works

When concrete containing ground slag is used for pavements, concreting works shall be done taking special care for curing of concrete.

[Commentary on 14.3]

It is not easy to keep concrete slabs, even if they are made of ordinary concrete, at favorable curing conditions. In view of the sensitivity of concrete containing ground slag to curing conditions and it's better performance characteristics after hardening, thorough care should be exercised during curing of concrete containing ground slag.

The concrete should be kept wet until the bending strength of the concrete attains 0.70 f'cr, as in the case of ordinary concrete. Tests are suggested to determine this period. When tests are not to be carried out, however, concrete should as a standard be kept for 21 days, although it differs somewhat with the replacement ratio. Concreting during cold weather sometimes makes this period insufficient.

As in the case of ordinary concrete, concrete containing ground slag should upon completion of surface finishing, be kept properly so that it will not be dried or exposed to direct sunlight and wind.

It is difficult for the ground slag to obtain the required strength when the weather is cold. It is necessary to keep the temperature of concrete within the range of 7 to 20°C during the placement and at least 7°C during curing, until the compressive strength attain 50 kgf/cm^2 or more so as to prevent the concrete from freezing.

The appropriate period and the time for the termination of curing as well as the removal of forms should be determined based on the results of the strength tests on specimens cured under conditions similar to those which the concrete to be placed at the site will be subjected.

CHAPTER 15 CONCRETE FOR DAMS

15.1 Scope of Application

This chapter provides the general requirements especially needed in concrete dams using concrete containing ground slag as an admixture.

[Commentary on 15.1]

Dams are massive and important structures. They must be able to endure severe weather conditions for many years and to maintain the required strength, durability, and water-tightness. The use of ground slag as an admixture of concrete is expected to result in concrete with a performance in terms of these requirements equal or superior to ordinary concrete. This chapter describes the matters to be noted when concrete containing ground slag is used in the construction of dams.

For the matters not specified in this chapter, the "Standard Specification for Design and Construction of Concrete Structures (Concrete Dams)" shall apply.

15.2 Ground Slag

Ground slag shall, in principle, conform to the requirements of the JSCE Standard "Ground Granulated Blast-Furnace Slag for Concrete". The ground slag, however, which does not meet the requirement of activity index at the age of 7 days may be used when it is clarified by tests that required properties of concrete can be obtained using the ground slag.

[Commentary on 15.2]

In order to control the rise in the temperature of concrete, it is desirable to use less fine ground slag. The JSCE's standard values were determined assuming the use of ground slag in general structures; the activity indices were determined considering that the strength development properties would not be remarkably deteriorated.

For some types of concrete, like that used for dams, the main purpose is to control the temperature rise of concrete. Large strength is not required at early stages, so it is desirable in many cases to use concrete with an activity index at the age of 7 days lower than the standard values specified in the JSCE Standard.

It was determined, therefore, that the concrete of which the activity index at the age of 7 days specified is lower than the values specified in the JSCE standards may be used for dam construction if it has been confirmed by tests that the required quality of concrete would be obtained.

15.3 Mix Proportion

When determining mix proportion of dam concrete, the mix proportion shall be determined so as to keep the temperature rise of concrete to a minimum within a range where the required strength, durability, water-tightness and the required workability can be satisfied.

[Commentary on 15.3]

In order to reduce the rise in temperature of concrete containing ground slag used for dams, the unit cementitious material content must be kept within the extent which satisfies the required quality and to select a mix proportion with which ground slag can be used at a high replacement ratio.

The unit cementitious material content of the concrete containing ground slag should be set at the same as for concrete not containing it.

It is desirable that the replacement ratio of ground slag be set within the range of 50 to 70% for the internal structures of dams and below 60% for the external structures of dams.

When ground slag is substituted at more than 60%, it is necessary in general to confirm by tests that concrete with the required quality will be obtained.

15.4 Concreting Works

When concrete containing ground slag is used for dams, concreting works shall be done taking special care for curing of concrete.

[Commentary on 15.4]

The development of strength of concrete containing ground slag is greatly affected by the mixing temperature and the curing temperature. Dams are often constructed in severe environments and thorough care should be exercised, especially when curing concrete constructed during cold weather.

As it is expected in the case of concrete used for the construction of dams that the temperature will rise due to the generation of heat during hardening, the temperature of concrete at the time of placement may be kept at 5°C or more instead of 7°C provided that the average day temperature is not less than 5°C and that the concrete will be thoroughly cured. When the temperature of concrete at the time of placement is less than 7°C, however, it is necessary to confirm by the tests, considering curing conditions, that concrete with the required quality can be obtained.