JSCE Guidelines for Concrete
No. 1

RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF CONCRETE STRUCTURES USING ELECTRIC ARC FURNACE OXIDIZING SLAG AGGREGATE

Japan Society of Civil Engineers

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Foreword

Electric arc furnace slag is generated during melting of iron scraps to produce steel, including oxidizing slag that forms in the oxidizing refining process and reducing slag that forms in the reducing refining process. Since these processes coexisted in electric arc furnaces up to the 1980s, it used to be difficult to separate oxidizing slag from reducing slag. Electric arc furnace slag could not be used as aggregate for concrete then, as free lime included in reducing slag and free magnesia from refractories caused concrete to expand to failure. Thanks to the separation of the oxidizing process from the reducing process in the 1980s to improve productivity and molten steel quality, however, it has become possible to separate oxidizing slag from reducing slag, enabling electric arc furnace slag to be utilized as aggregate for concrete.

To promote the use of electric arc furnace slag, which amounts to 2 million tons annually, a standard was formulated for this slag and published as Part 4 of JIS A 5011 (Slag aggregate for concrete) in June 2003.

Accepting a commission from the Nippon Slag Association, the JSCE Concrete Committee organized the Committee on Electric Arc Furnace Oxidizing Slag Aggregate Concrete to launch research activities with the aim of formulating recommendations for design and construction using such concrete at the commencement stage of the study for standardization of electric arc furnace slag aggregate.

This volume of Concrete Library includes the achievements of the committee, namely, the Recommendations for Design and Construction, the Proportioning Manual and the test method for density and water absorption of slag aggregate for concrete by measurement of electric resistance, as well as references, such as JIS A 5011-4 (Slag aggregate for concrete – Part 4: Electric arc furnace oxidizing slag) and technical data related to electric arc furnace oxidizing slag aggregate and concrete containing such slag. We believe that these recommendations, the manual and various data will be useful as guidelines for using electric arc furnace slag aggregate for construction of concrete structures.

We hope that these recommendations will contribute to the sound popularization of concrete made using electric arc furnace slag aggregate and effective use of aggregate resources. Last but not in the least, I would like to express my sincere gratitude to the committee members who enthusiastically carried out the research activities, particularly to Dr. Tatsuhiko Saeki, the secretary, for his considerable efforts for the management of the committee and publishing of this volume of the Concrete Library.

I would like to express my gratitude to the ISO Technical Standard Committee chaired by Dr. Shigeyoshi NAGATAKI, for financial support to publish this English version of the Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate.

April 2004

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RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF CONCRETE STRUCTURES USING ELECTRIC ARC FURNACE OXIDIZING SLAG AGGREGATE

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PART I RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION

CHAPTER 1 GENERAL

1.1 Scope

These Recommendations present general standards for design and construction of concrete in which electric arc furnace (EAF) oxidizing slag coarse aggregate, gravel or crushed stone is singly used as coarse aggregate and EAF oxidizing slag fine aggregate is used in combination with sand or crushed sand as fine aggregate. As to matters not specified herein, the *Standard Specifications for Concrete Structures 2002* (hereafter referred to as the *Standard Specifications*), *Materials and Construction*, JSCE, shall apply.

[Commentary]

Electric arc furnace (EAF) slag is generated as a by-product when iron scrap is melted in EAFs to produce crude steel. In Japan, oxidizing slag and reducing slag from EAFs are generated total 3,500,000 tons annually. EAF oxidizing slag, which is produced by slow cooling or quenching oxidizing slag formed during the melting/oxidizing process, amounts to 2,000,000 tons, accounting for 60% of the total EAF slag production. Since EAF oxidizing slag is composed of stable minerals such as the dicalcium silicate phase, it can be used as a sound material for concrete aggregate. On the other hand, EAF reducing slag contains a high percentage of free lime, which can cause popout and expansive failure of concrete. For this reason, EAF reducing slag cannot be used as aggregate for concrete.

Research into the use of EAF oxidizing slag for concrete aggregate, which began in 1996 at the Nippon Slag Association, ascertained that EAF oxidizing slag is sufficiently feasible as aggregate for concrete, leading to the establishment of JIS A 5011-4 (Slag aggregate for concrete, Part 4: Electric arc furnace oxidizing slag aggregate) in 2003. EAF oxidizing slag conforming to JIS with no reducing slag inclusion is produced in plants certified as JIS-accredited plants where the processes and state of control are subject to inspection. Only EAF oxidizing slag produced in such plants can be used for concrete aggregate.

Active use of EAF oxidizing slag for concrete aggregate is anticipated from the aspect of the effective use of industrial by-products and mitigation of the environmental loads. When used for adjusting the grading of inadequately graded sand, EAF oxidizing slag will serve as an aggregate resource that rectifies natural aggregate, thereby remarkably contributing to measures against depletion of natural aggregate in the area. Moreover, the qualities of sea sand, pit sand or crushed sand that cannot be used as fine aggregate by itself due to nonconformity regarding the chloride content and grading can be improved by blending an appropriate percentage of EAF oxidizing slag fine aggregate of an adequate grading class specified in JIS.

These Recommendations cover concrete made using EAF oxidizing slag coarse aggregate, gravel or crushed sand singly as coarse aggregate and EAF oxidizing fine aggregate as fine aggregate in combination with sand or crushed sand. EAF oxidizing slag aggregate refers to that conforming to oven-dry density class N of JIS, for which there has been field experience including trial construction. For concrete containing EAF oxidizing slag aggregate, these Recommendations specify as general standards the upper limits of volumetric ratios of EAF oxidizing slag fine aggregate to be 50% when crushed stone or gravel is used singly as coarse aggregate and 30% when EAF oxidizing slag coarse aggregate is used singly as coarse aggregate. Particularly when gravel or crushed stone is used as coarse aggregate, concrete made using EAF oxidizing slag fine aggregate up to 30% by volume of the total fine aggregate content can be proportioned and used similarly to normal concrete.

These Recommendations do not cover EAF oxidizing slag designated as JIS oven-dry density class H. Even when EAF oxidizing slag conforming to class N requirements is used, combinations of fine and coarse aggregates out of the specified range or combinations with other types of aggregate are not covered by these Recommendations, due to insufficient field experience and reference data. Also, the use of EAF oxidizing slag aggregate for concrete with a characteristic value of the compressive strength of over 60 N/mm^2 and prestressed concrete are excluded from the scope of these Recommendations for similar reasons.

Matters not specified in these Recommendations should comply with the *Standard Specifications for Concrete Structures 2002, Materials and Construction or Structural Performance Verification*, or subject to sufficient investigation for quality confirmation, including tests and research referring to these

Recommendations. Since EAF oxidizing slag is a new material, points of note during mixture proportioning of concrete containing this type of slag are summarized as a Proportioning Manual for the convenience of users. This Manual is attached to these Recommendations as Part II.

1.2 Definitions

The following terms are defined for general use in these Recommendations:

normal fine aggregate:

Generic term for sand and crushed sand used as fine aggregate.

normal coarse aggregate:

Generic term for gravel and crushed stone used as coarse aggregate.

electric arc furnace (EAF) oxidizing slag fine aggregate:

Molten oxidizing slag formed in an electric arc furnace during the production of steel, which is then slowly cooled or quenched, crushed, with iron (metallic iron) being removed by magnetic separation, and graded to be suitable as fine aggregate for concrete.

electric arc furnace (EAF) oxidizing slag coarse aggregate:

Molten oxidizing slag formed in an electric arc furnace during the production of steel, which is then slowly cooled, crushed, with iron (metallic iron) being removed by magnetic separation, and graded to be suitable as coarse aggregate for concrete.

blended electric arc furnace (EAF) oxidizing slag fine aggregate:

A blend of electric arc furnace slag fine aggregate and normal fine aggregate at a specified ratio.

electric arc furnace (EAF) oxidizing slag fine aggregate ratio (EAF slag ratio):

Absolute volumetric ratio in percentage of EAF oxidizing slag fine aggregate to the total fine aggregate in blended EAF oxidizing slag fine aggregate.

electric arc furnace (EAF) oxidizing slag aggregate concrete:

Generic term for concrete made using EAF oxidizing slag aggregate as part or all of its aggregate.

normal aggregate concrete:

Generic term for concrete made using normal fine aggregate and normal coarse aggregate for fine and coarse aggregate, respectively.

[Commentary]

Normal fine aggregate: In these Recommendations, sand, such as river sand, pit sand and sea sand, as well as crushed sand, are generically referred to as normal fine aggregate.

Normal coarse aggregate: In these Recommendations, natural gravel of various kinds represented by river gravel, as well as crushed stone, are generically referred to as normal coarse aggregate.

EAF oxidizing slag fine aggregate: EAF oxidizing slag aggregate is made from molten oxidizing slag formed during the production of steel in an electric arc furnace using iron scrap as the main material. The slag is slowly air-cooled or spray-quenched as it is splashed in the air in a rotating drum. Since EAF oxidizing slag fine aggregate contains iron oxides (FeO_2, Fe_2O_3) and metallic iron (Fe), most of metallic iron is removed by magnetic separation from air-cooled slag crushed by rod mill or from quenched slag made into granules.

EAF oxidizing slag coarse aggregate: This is EAF oxidizing slag discharged from an electric arc furnace, which is then air-cooled and crushed, with metallic iron being removed by magnetic separation similarly to fine aggregate, and graded to be suitable as coarse aggregate for concrete.

Blended EAF oxidizing slag fine aggregate: When blending EAF oxidizing slag fine aggregate with pit sand or sea sand for the purpose of adjusting the grading, reducing the chloride content, etc., it can be blended at an appropriate ratio beforehand as a premixed fine aggregate or separately batched and mixed with other materials in a mixer at the time of concrete mixing. The latter (mixing at the time of concrete mixing) is recommended in these Recommendations.

EAF oxidizing slag fine aggregate ratio: The absolute volumetric ratio of EAF oxidizing slag fine aggregate to the total amount of blended fine aggregate in percentage is referred to as the EAF oxidizing slag fine aggregate ratio (hereafter referred to as EAF slag ratio in the commentaries).

EAF oxidizing slag aggregate concrete: Concrete made using EAF oxidizing slag aggregate as part or all of its aggregate is generically referred to as EAF oxidizing slag aggregate concrete.

Normal aggregate concrete: Concrete made using normal fine aggregate, such as river sand, land sand, crushed sand and sea sand, for all of its fine aggregate and normal coarse aggregate, such as gravel and crushed stone, for all of its coarse aggregate is generically referred to as normal aggregate concrete.

CHAPTER 2 QUALITY OF EAF OXIDIZING SLAG AGGREGATE CONCRETE

2.1 General

EAF oxidizing slag aggregate concrete shall provide the required strength, durability, density, watertightness, resistance to cracking and other performances, with minimal variation in quality. It shall also provide suitable workability during concreting work.

[Commentary]

When gravel or crushed stone is used for all of the coarse aggregate, the properties of concrete containing class N EAF oxidizing slag fine aggregate at an EAF slag ratio of less than 30% can be regarded as equivalent to those of normal aggregate concrete as stated in Chapter 1. The combination of 100% normal coarse aggregate and EAF oxidizing slag fine aggregate with an EAF slag ratio between 30% and 50% and the combination of 100% EAF oxidizing slag coarse aggregate and EAF oxidizing slag fine aggregate with an EAF slag ratio less than 30% are prone to segregation and increases in the unit water content. Precautions provided in these Recommendations should therefore be observed in mixture proportioning and placing of such concretes to make good concrete. It should be noted that these Recommendations do not intend to limit the use of concretes other than the above-mentioned combinations. Class H aggregate and a higher EAF slag ratio may be employed provided that achievement of the required qualities of concrete is confirmed, e.g., by experiment.

The qualities of EAF oxidizing slag aggregate concrete are summarized as follows:

<u>Fresh concrete</u>: For EAF oxidizing slag aggregate concrete, the unit water content necessary for attaining the required slump increases as the slag aggregate content increases. The amount of bleeding water of EAF oxidizing slag aggregate concrete is greater than that of normal concrete, as the water-retaining capability of the aggregate is low due to the high density and smooth surfaces, in addition to the increase in the unit water content and the resulting retardation in setting. It is therefore important to take measures to minimize bleeding by the use of an air-entraining and water-reducing admixture and various mineral powders. Also, the use of an EAF oxidizing slag fine aggregate with a high percentage of fraction passing a 0.15-mm sieve is effective in reducing the unit water content and the amount of bleeding water.

In the case of a combination of normal coarse aggregate and less than 30% EAF oxidizing slag fine aggregate, the pumpability of concrete may be regarded as similar to normal aggregate concrete.

Density: The oven-dry density of EAF oxidizing slag aggregate ranges between 3.1 and 4.5 g/cm^3, which is much greater than that of normal aggregate. For this reason, the density of concrete increases as the EAF oxidizing slag aggregate content increases. Whereas the combination of an EAF slag ratio of less than 30% and normal coarse aggregate only increases the density by about 100 kg/m^3 compared with typical normal aggregate concrete, the density of concrete in which all fine and coarse aggregates consist of EAF oxidizing slag aggregate amounts to around 3,000 kg/m^3.

Strength: The compressive strength of EAF oxidizing slag aggregate concrete can be lower than normal aggregate concrete up to an age of 3 days depending on the aggregate brand, but becomes equal to or slightly higher than normal aggregate concrete thereafter. The strength tends to be higher as the slag aggregate content increases.

The compressive strength-related properties of EAF oxidizing slag aggregate concrete have been sufficiently confirmed in the range of up to 60 N/mm^2. It can be treated similarly to normal aggregate concrete in this strength range.

Durability: EAF oxidizing slag aggregate concrete should be made as air-entrained concrete having an adequate air content to ensure durability against freezing and thawing action. Resistance to frost damage of this type of concrete can be achieved by taking adequate measures, such as controlling bleeding, reducing the water-cement ratio and increasing the air content, in the range of the EAF oxidizing slag aggregate content covered by the present Recommendations, regardless of the EAF slag ratio.

Due to the generally low silica content in EAF oxidizing slag, the risk of concrete deterioration induced by alkali-aggregate reaction may be regarded as marginal.

Watertightness: In order to ensure watertightness of EAF oxidizing slag aggregate concrete, it is important to control the amount of bleeding water by reducing the water-cement ratio and slump.

Resistance to cracking: It is important to control the amount of bleeding water as strictly as possible to prevent settlement cracking of EAF oxidizing slag aggregate concrete.

Due to its great density, the heat capacity of EAF oxidizing slag is large, tending to reduce the adiabatic temperature rise and rise rate. EAF oxidizing slag aggregate concrete is therefore relatively advantageous over normal aggregate concrete in regard to thermal cracking.

The drying shrinkage of EAF oxidizing slag aggregate concrete is generally smaller than that of normal aggregate concrete.

CHAPTER 3 CONSTRUCTION PLANNING

3.1 Construction planning for concreting work

(1) In concreting using EAF oxidizing slag aggregate, an appropriate construction planning for concreting work shall be formulated in consideration of the qualities of the EAF oxidizing slag aggregate to be used.

(2) The construction planning for concreting work shall as a rule be formulated in accordance with the *Standard Specifications, Materials and Construction.*

[Commentary]

(1) EAF oxidizing slag aggregate concrete is characterized by its tendencies toward greater slump losses during transportation from the concrete plant to the construction site, longer setting times and larger amounts of bleeding water than those of normal aggregate concrete. It is therefore vital to formulate a construction planning for concreting work giving careful consideration to the qualities of EAF oxidizing slag aggregate concrete. It is advisable to confirm the properties related to slump losses, segregation, pumpability and setting times by trial mixtures and placing tests as required before formulating the final construction plan, since field experience to date has not necessarily been sufficient to cover wide varieties of environmental and construction conditions.

EAF oxidizing slag aggregate should as a rule be a product from one single plant. When circumstances dictate the use of aggregates from more than one plant, it is essential not only to grasp the quality fluctuation of aggregate beforehand but also to confirm the feasibility of constant production of uniform concrete having the required qualities by tests on trial mixtures.

(2) The use of EAF oxidizing slag aggregate concrete is an effective means to mitigate the environmental loads from the aspect of protecting natural aggregate resources, since it is itself a utilization of an industrial by-product. It is therefore desirable to carry out concreting while exercising care to reduce the environmental loads.

In the design of formwork and shoring, the design values for lateral pressure shall be determined based on field experience or by preliminary testing before execution, since the density of fresh concrete containing EAF oxidizing slag aggregate becomes greater than that of normal aggregate concrete.

3.2 Establishment of concreting methods

The methods assumed at the design stage may be established at the time of formulating the construction plan as the concreting methods for EAF oxidizing slag aggregate concrete, including methods of conveyance within the job site, placing, consolidation, finishing, curing and jointing lifts, similarly to the requirements for normal concrete in the *Standard Specifications, Materials and Construction*. However, other methods provided in Chapter 7 can be more appropriate in certain cases depending on the structural, construction or environmental conditions. In such a case, it is advisable to select and establish such methods.

3.3 Verification of construction planning

(1) A construction planning for concreting work involving EAF oxidizing slag aggregate shall be subject to verification by appropriate methods as to whether the plan will satisfy the construction requirements and performance requirements of the structure.

(2) Verification of a construction plan shall be in accordance with the *Standard Specifications, Materials and Construction* as a standard and shall be carried out by confirming that the formulated construction plan provides sufficient margins for the expected fluctuations in the construction.

(3) When adopting methods provided in Chapter 7 (Concreting work), verification may be omitted.

3.4 Change in the planning

When changes in the construction methods become necessary in the process of construction involving EAF oxidizing slag aggregate concrete, the construction plan shall be modified, while ensuring the attainment of the construction requirements and performance requirements. The new construction plan shall be verified, and the documents of the construction plan shall be updated.

CHAPTER 4 PLACEMENT-RELATED PERFORMANCES OF CONCRETE

4.1 General

EAF oxidizing slag aggregate concrete shall possess the placement-related performances suitable for concreting work, including conveyance, placement, consolidation, finishing and form removal under the specific construction, structural and environmental conditions.

4.2 Workability

(1) The workability of EAF oxidizing slag aggregate concrete shall be suitable for concreting work including conveyance, placement, consolidation and finishing.

(2) For workability, the maximum aggregate size and slump shall be established in consideration of the conditions of the structure, such as the dimensions and reinforcing bars arrangement, construction methods and risk of concrete segregation. The slump values specified in the *Standard Specifications, Materials and Construction* may be adopted as a standard for a general structure under standard construction conditions.

(3) The method of verifying the workability shall comply with the *Standard Specifications, Materials and Construction*, as a standard.

[Commentary]

Due to the density of EAF oxidizing slag aggregate being higher than that of normal aggregate, the consistency of EAF oxidizing slag aggregate concrete could be stiffer than that of normal aggregate concrete having a similar slump, but no significant difference has been observed in studies conducted to date. According to field experience of EAF oxidizing slag aggregate concrete, the slump loss during conveyance immediately after mixing tends to be large, but the sump loss during pumping is similar to that of normal aggregate concrete.

The segregation resistance may be regarded as similar to that of normal aggregate concrete for a combination of normal coarse aggregate and blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 50%. However, it is vital to control the amount of bleeding water by ensuring a suitable fines content, as it tends to increase when EAF oxidizing slag aggregate is used.

4.3 Pumpability

(1) The pumpability of EAF oxidizing slag aggregate concrete shall be suitable for the pumping work.
(2) Pumpability may be established by the pressure loss per m of horizontal piping.

[Commentary]

(1) The pumpability of concrete made using normal coarse aggregate and blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30% may be regarded as similar to that of normal aggregate concrete. However, due to the angular shapes of EAF oxidizing slag aggregate, a high slag content tends to increase the risk of blockage during pumping. It is therefore important to ensure adequate viscosity by, e.g., securing the air content and fines content in the mixture to prevent blockage of piping.

(2) When the EAF slag ratio in the fine aggregate is 30% or more or when EAF oxidizing slag is used as the coarse aggregate, it is advisable to limit the product of the pressure loss per m of horizontal piping and the equivalent horizontal pumping distance to be within 70% the maximum theoretical discharge of the concrete pump.

4.4 Setting

(1) Consolidation, placing on consolidated fresh concrete and finishing of EAF oxidizing slag aggregate concrete shall be properly carried out in consideration of its setting properties.

(2) The setting properties may be established by the initial and final setting times.

[Commentary]

Setting of EAF oxidizing slag aggregate concrete tends to retard when compared with normal aggregate concrete. According to measurement results, initial setting times range between 5 and 8 hours, and final setting times range between 8 and 11 hours.

4.5 Strength required during construction

(1) Concrete shall possess the strength required during construction.

(2) The compressive strength necessary for removal of formwork and shoring shall be determined in consideration of the bulk density of EAF oxidizing slag aggregate concrete, which is higher than that of normal aggregate concrete.

[Commentary]

The bulk density of EAF oxidizing slag aggregate concrete generally becomes higher than that of normal aggregate concrete. For this reason, formwork and shoring must not be removed until the concrete attains a strength sufficient for withstanding its own weight when the slag content is high in fine and/or coarse aggregate. However, in the case of concrete made using normal coarse aggregate and blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30%, the strength for form removal may be determined in accordance with the *Standard Specifications, Materials and Construction.*

CHAPTER 5 PROPORTIONING OF CONCRETE

5.1 General

The materials and mixture proportions of EAF oxidizing slag aggregate concrete shall be established to achieve the required performance of concrete in consideration of the restricting conditions of the batching and mixing plant and economic efficiency including the material availability and transportation cost.

[Commentary]

The properties of EAF oxidizing slag aggregate concrete related to compressive strength and durability may be regarded as similar to those of normal aggregate concrete excepting the resistance to freezing and thawing and water permeability. Therefore, basically the relative elastic modulus and coefficient of water permeability should be verified in accordance with 5.4, while other concrete performances should be verified in accordance with the *Standard Specifications, Materials and Construction.*

These Recommendations provide Part II (Proportioning Manual). This manual was formulated based on the experience in the construction of structures made of EAF oxidizing slag aggregate concrete and the results of laboratory tests on such concrete obtained to date. When proportioning a standard EAF oxidizing slag aggregate concrete, it is advisable to refer to this manual.

5.2 Fine aggregate

5.2.1 General

EAF oxidizing slag fine aggregate, normal fine aggregate and blended EAF oxidizing slag fine aggregate as a standard shall be clean, hard, durable and well-graded without deleterious amounts of dust, mud, organic impurities, chlorides and other harmful substances.

[Commentary]

EAF oxidizing slag fine aggregate: Fine aggregate conforming to JIS A 5011-4 is capable of producing sound concrete with high quality, provided it is used with thorough understanding of its qualities and strict control to prevent inclusion of deleterious material during transportation and storage.

Blended EAF oxidizing slag fine aggregate: While the availability of good natural fine aggregate has been decreasing in recent years, there are abundant supplies of fine aggregates failing to meet the *Standard Specifications, Materials and Construction*, yet potentially usable as fine aggregate for concrete subject to adjustment of the grading and/or reduction in the chloride content. Good-quality fine aggregate for concrete can be obtained by blending such normal fine aggregate with adequate EAF oxidizing slag fine aggregate. However, normal fine aggregate failing to meet the density or water absorption requirements must not be blended with EAF oxidizing slag fine aggregate.

When EAF oxidizing slag fine aggregate is blended beforehand, it is generally difficult to confirm by testing the pre-blend qualities of the component fine aggregates and the uniformity of aggregate after blending. For this reason, when producing concrete, the following method is recommended: Store EAF oxidizing slag fine aggregate and normal fine aggregate separately, batch them separately according to the EAF slag ratio and blend them in the mixer bowl at the time of concrete mixing.

5.2.2 EAF oxidizing slag fine aggregate

5.2.2.1 General

EAF oxidizing slag fine aggregate conforming to JIS A 5011-4 shall be used.

5.2.2.2 Grading

(1) The grading range of EAF oxidizing slag fine aggregate shall be as given in Table 5.2.1. Sieve analysis shall be conducted in accordance with JIS A 1102.

Table 5.2.1 Grading range of EAF oxidizing slag fine aggregate (JIS A 5011-4)

Nominal sieve size (mm) / Type	Mass percentage of fraction passing sieve (%)						
	10	5	2.5	1.2	0.6	0.3	0.15
5-mm EAF oxidizing slag fine aggregate	100	90-100	80-100	50-90	25-65	10-35	2-15
2.5-mm EAF oxidizing slag fine aggregate	100	95-100	85-100	60-95	30-70	10-45	5-20
1.2-mm EAF oxidizing slag fine aggregate	-	100	95-100	85-100	35-80	15-50	10-30
5-0.3-mm EAF oxidizing slag fine aggregate	100	95-100	45-100	10-70	0-40	0-15	0-10

(2) The fineness modulus of EAF oxidizing slag fine aggregate shall not differ by ± 0.20 from that specified at the time of purchase agreement.

[Commentary]

In order to achieve good workability with a minimum unit water content, it is desirable to select an EAF oxidizing slag fine aggregate of slightly fine grading with a fineness modulus of around 2.3.

EAF oxidizing slag fine aggregate comes in several gradings to permit blending with any of fine-, medium- and coarse-grain normal fine aggregates. It should be noted that 5-mm and 2.5-mm EAF oxidizing slag fine aggregates can also be used by themselves as fine aggregate for concrete.

An increase in the content of fines below 0.15 mm included in EAF oxidizing slag scarcely increases the unit water content, as the fines do not consist of clay or silt. Fines in EAF oxidizing slag fine aggregate also have an effect of controlling bleeding. When it is desired to reduce the amount of concrete bleeding in such a case as employing a high EAF slag ratio, it is advisable to select and use an EAF oxidizing slag fine aggregate having a high fines content with a size of 0.15 mm or less. In consideration of this point, JIS A 5011-4 permits high percentages of fraction passing a 0.15-mm sieve of 5 to 20% and 10 to 30% for 2.5-mm and 1.2-mm EAF oxidizing slag fine aggregates, respectively.

5.2.3 Normal fine aggregate

Normal fine aggregate to be blended with EAF oxidizing slag fine aggregate as a standard shall be that conforming to the requirements of the *Standard Specifications, Materials and Construction,* excepting the requirements for grading and chloride content.

[Commentary]

One of the purposes of these Recommendations is to have normal fine aggregates having inadequate grading and/or chloride content partially exceeding the permissible limit turned into good quality fine aggregate by being blended with EAF oxidizing slag fine aggregate, thereby effectively utilizing unused resources. Even when EAF oxidizing slag fine aggregate is blended for this purpose, the physical properties of normal fine aggregate to be blended should be acceptable.

5.2.4 Blended EAF oxidizing slag fine aggregate

5.2.4.1 General

(1) When blending EAF oxidizing slag fine aggregate with normal fine aggregate in a mixer at the time of concrete mixing, care shall be exercised to ensure the specified EAF slag ratio.

(2) Premixed EAF oxidizing slag fine aggregate shall be such that the qualities of each component fine aggregate can be confirmed by a certificate of test results, with the target EAF slag ratio defined, and that EAF oxidizing slag fine aggregate and normal fine aggregate are uniformly blended.

[Commentary]

(1) When blending EAF oxidizing slag fine aggregate with normal fine aggregate with the aim of adjusting the grading and chloride content of normal fine aggregate, it is important to precisely measure each aggregate at the time of blending and uniformly blending the aggregates to achieve the specified EAF slag ratio. For this reason, blending both aggregates in the mixer at the time of concrete mixing is recommended in the present Recommendations.

(2) In the case of premixed EAF oxidizing slag fine aggregate, it is vital for its proper use that the qualities of the component fine aggregates before blending and the target EAF slag ratio are documented.

Since a large amount of fine aggregate is blended when using blended EAF oxidizing slag fine aggregate, great care should be exercised for blending the component aggregates measured according to the specified EAF slag ratio to achieve a uniform blend.

5.2.4.2 EAF oxidizing slag fine aggregate ratio

The ratio of EAF oxidizing slag fine aggregate as a standard shall be suitably established based on testing to achieve concrete having the required qualities.

[Commentary]

The present Recommendations recommend an EAF slag ratio of less than 50% and provide requirements in two levels: 0 to 30% and 30 to 50%. In the case of an EAF slag ratio exceeding 50%, these Recommendations require confirmation by testing so that the resulting concrete can achieve the required placement-related performances while fresh and performances after hardening.

EAF oxidizing slag fine aggregate comes in four grading types: standard, medium-, coarse- and fine-grain. The grading of fine aggregate for concrete can be adjusted by suitably selecting these types depending on the grading of normal fine aggregate and blending at an adequate ratio.

According to test results to date, fine aggregate with an EAF slag ratio of less than 30% can be treated similarly to normal fine aggregate, and the qualities of the resulting concrete are ascertained to be similar to those of normal aggregate concrete.

5.2.4.3 Grading

(1) The grading of blended EAF oxidizing slag fine aggregate in a uniformly blended state shall be in the range of Table 5.2.2 as a standard.

Table 5.2.2 Standard grading of blended EAF oxidizing slag fine aggregate

Nominal sieve size (mm)	Volume percentage of fraction passing sieve (%)	Nominal sieve size (mm)	Volume percentage of fraction passing sieve (%)
10	100	0.6	25-65
5	90-100	0.3	10-35
2.5	80-100	0.15	2-15[1)]
1.2	50-90	-	-

1) The upper limit shall be 15% for premixed fine aggregate. The upper limit may be increased to 20% for separate measurement at the time of concrete mixing. However, in no case shall the percentage from sand and crushed sand exceed 10% and 15%, respectively.

(2) The fineness modulus of blended EAF oxidizing slag fine aggregate shall not differ from the value specified at the time of purchase agreement by more than ± 0.20.

[Commentary]

Generally speaking, good concrete can be produced when typical grading of a blended EAF oxidizing slag fine aggregate is in the range specified in Table 5.2.2 and the fluctuation of the distribution is marginal. When a blended EAF oxidizing slag fine aggregate with a high EAF slag ratio has to be used, it is advisable to set a slightly lower value for the target fineness modulus of around 2.3 than normal values of 2.6 to 2.8.

Fines less than 0.15 mm contained in EAF oxidizing slag fine aggregate are not clay or silt, which is deleterious to concrete quality, but are found to contribute to control of bleeding. In this light, the upper limit of the volume percentage of fraction passing a 0.15-mm sieve was permitted up to 15% for blended EAF oxidizing slag fine aggregate. For the case where each component fine aggregate is measured separately at the time of concrete mixing, the upper limit was increased to 20%, as the quality of each material before blending can be thoroughly confirmed and the reliability of the blend ratio increases.

When the density of an EAF oxidizing slag fine aggregate widely differs from that of normal fine aggregate to be blended, it is appropriate to express the size distribution by the absolute volume in each sieve range.

5.2.4.4 Chloride content limit

The chloride content of blended EAF oxidizing slag fine aggregate shall satisfy the standards of chloride content limits for fine aggregate specified in the *Standard Specifications, Materials and Construction* in the uniformly blended state.

[Commentary]

If the component EAF oxidizing slag fine aggregate meets the quality requirements specified in 5.2.2 and the component normal fine aggregate meets the quality requirements specified in 5.2.3, then the qualities of the resulting blended EAF oxidizing slag fine aggregate may generally be regarded as having good quality as fine aggregate for concrete excepting the items related to grading and chloride content.

Since no seawater is involved in the cooling and other production processes, no chloride gains access to EAF oxidizing slag fine aggregate. For this reason, the chloride content of normal fine aggregate can be reduced by blending with EAF oxidizing slag fine aggregate at an adequate ratio.

The chloride content of blended EAF oxidizing slag fine aggregate can be calculated from the chloride content of each component fine aggregate before blending and the EAF slag ratio. When testing is to be conducted, it is advisable to follow the method specified in JSCE-C502 (Test method for chloride ion content in sea sand (Titration method)).

5.3 Coarse aggregate

5.3.1 General

EAF oxidizing slag coarse aggregate and normal coarse aggregate as a standard shall be clean, hard, durable and well-graded without thin fragments or long and narrow fragments of stone or deleterious amounts of dust, mud, organic impurities, chlorides and other harmful substances.

[Commentary]

Since it is not deemed necessary to blend two or more coarse aggregates for concrete, when EAF oxidizing slag coarse aggregate is to be used, its use by itself is required as a standard, as stated in 1.1. Where it is necessary to blend more than one coarse aggregate, the blend may be used after examining the blend ratio and mixture proportions by testing.

5.3.2 EAF oxidizing slag coarse aggregate

5.3.2.1 General

EAF oxidizing slag coarse aggregate shall conform to JIS A 5011-4.

5.3.2.2 Grading

(1) The grading range of EAF oxidizing slag coarse aggregate shall be as given in Table 5.3.1. Sieve analysis shall be conducted in accordance with JIS A 1102.

Table 5.3.1 Grading range of EAF oxidizing slag coarse aggregate (JIS A 5011-4)

Nominal sieve size (mm) / Type	Mass percentage of fraction passing sieve (%)						
	50	40	25	20	15	10	5
EAF oxidizing slag coarse aggregate 4020	100	90-100	20-55	0-15	-	0-5	-
EAF oxidizing slag coarse aggregate 2005	-	-	100	90-100	-	20-55	0-10
EAF oxidizing slag coarse aggregate 2015	-	-	100	90-100	-	0-10	0-5
EAF oxidizing slag coarse aggregate 1505	-	-	-	100	90-100	40-70	0-15

(2) The fineness modulus of EAF oxidizing slag coarse aggregate shall not differ by ± 0.30 from that specified at the time of purchase agreement.

[Commentary]

The grading ranges of EAF oxidizing slag coarse aggregate are the same as those of four types specified in JIS A 5011-4.

The most widely used grading of EAF oxidizing slag coarse aggregate is EFG 20-05. For maintaining stability in the grading of EAF oxidizing slag coarse aggregate, it is advisable to store and measure EFG 20-15 and EFG 15-05 separately and blend for use at the time of concrete mixing. When the maximum size is set at 40 mm as used for concrete armor units, a combination of EFG 40-20 and EFG 20-05 or a combination of EFG 40-20, EFG 20-15 and EFG 15-05 at adequate proportions should be uniformly blended for use. The grading of blended coarse aggregate should conform to the values specified in Table 6.2.3 in 6.2.5.3 of the *Standard Specifications, Materials and Construction*, as a standard.

5.3.3 Normal coarse aggregate

Normal coarse aggregate to be used for EAF oxidizing slag aggregate concrete shall conform to the requirements of the *Standard Specifications, Materials and Construction.*

5.4 Performance verification of concrete

5.4.1 General

Concrete made using selected materials and mixture proportions shall be subject to verification to confirm fulfillment of the performance requirements.

[Commentary]

Though with limited field experience, the results of laboratory tests have revealed that EAF oxidizing slag aggregate concrete possesses performances comparable to normal aggregate concrete excepting resistance to freezing and thawing and water permeability. For this reason, verification of the performances of EAF oxidizing slag aggregate concrete is required basically in accordance with the *Standard Specifications, Materials and Construction*, excepting the verification of relative dynamic modulus and water permeability.

5.4.2 Verification of relative dynamic modulus

When a risk of deterioration due to repeated freezing and thawing action is assumed for concrete for which fine and coarse aggregate conforming to 5.2 and 5.3, respectively, of these Recommendations are selected together with standard concrete materials conforming to the *Standard Specifications, Materials* *and Construction*, the relative dynamic modulus shall be verified as given below, unless verified by testing in accordance with JIS A 1148.

Verification of relative dynamic modulus may be substituted by confirmation that the water-cement ratio (water-binder ratio) is not more than the values specified in Table 5.4.1 and that the air content is in the range of 5 to 7%.

Table 5.4.1 Upper limits of water-cement ratio of air-entrained concrete for determination of water-cement ratio based on freezing and thawing resistance of EAF oxidizing slag aggregate concrete (%)

Climatic conditions / Cross-section / Exposure level of structur	Fierce climatic action or frequently repeated freezing and thawing		Climatic action is mild; Temperatures rarely drop below 0°C	
	Thin[2]	Normal	Thin[2]	Normal
(1) Continuously or frequently saturated with	55 (85)	60 (70)	55 (85)	65 (60)
(2)Normal exposure conditions other than (1)	60 (70)	65 (60)	60 (70)	65 (60)

Values in ( ) are relative dynamic modulus required for concrete (%)

1) Parts of waterways, water tanks, abutments, bridge piers, retaining walls, tunnel lining, etc., that are located near water surfaces and saturated with water. Parts of beams, slabs, etc., of these and other structures saturated with water by snowmelt, flowing water, splashes, etc., though located away from water surfaces.

2) Parts of structures with a cross-sectional thickness of up to around 20 cm, etc.

[Commentary]

The resistance to freezing and thawing of EAF oxidizing slag aggregate concrete is slightly lower than that of normal aggregate concrete when normal coarse aggregate is combined with blended EAF oxidizing slag fine aggregate with an EAF slag ratio between 30 and 50% and when EAF oxidizing slag coarse aggregate is combined with blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30%. However, laboratory tests have revealed that the resistance becomes comparable to that of normal aggregate concrete when an air content of 5% or more is ensured. On the other hand, when normal coarse aggregate is combined with blended EAF oxidizing fine aggregate with an EAF slag ratio of less than 30%, the freeze-thaw resistance of the resulting concrete may be regarded as comparable to that of normal aggregate concrete with little adverse effect of EAF oxidizing fine aggregate.

Laboratory tests have revealed that an amount of bleeding water exceeding 0.4 cm^3/cm^2 reduces the resistance to freezing and thawing of EAF oxidizing slag aggregate concrete. It is therefore advisable to select the materials and mixture proportions to control the amount of bleeding water at 0.4 m^3/cm^2 or less to ensure the required resistance to freezing and thawing. It is preferable to set a target water-cement ratio around 5% lower than the value given in Table 5.4.1, particularly when a large amount of bleeding water is expected by the use of EAF oxidizing slag coarse aggregate in combination with blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30%,

When concrete is exposed to the effect of chlorides in deicing salts and seawater, scaling can occur in the structure. In such a case, it is advisable to reduce the water-cement ratio to 40% or less, while increasing the air content to 7% or more.

5.4.3 Verification of coefficient of water permeability

The water permeability of concrete for which standard materials are selected may be verified by ascertaining that the water-cement ratio (water-binder ratio) is 50% or less, unless verified by water permeation testing of concrete.

[Commentary]

Since EAF oxidizing slag aggregate concrete can generate a large amount of bleeding water, its watertightness can be lower than that of normal aggregate concrete. The water-cement ratio is therefore required to be 5% lower than the value specified in 6.4.8 (2) of the *Standard Specifications, Materials and Construction.*

CHAPTER 6 MIXING AND READY-MIXED CONCRETE

6.1 Storage of aggregate

EAF oxidizing slag aggregate, normal fine aggregate and blended EAF oxidizing slag aggregate shall be separately stored, with different types and gradings being divided.

6.2 Batching and mixing

(1) Each material to be used for EAF oxidizing slag aggregate concrete shall be accurately batched so

that concrete with the specified qualities can be obtained.

(2) The sequence of charging materials in the mixer and the mixing time shall be adequately established beforehand.

(3) The batch size shall be determined in consideration of the capacity of the transportation vehicle.

[Commentary]

A volume of EAF oxidizing slag aggregate concrete equal to the amount normally hauled by a vehicle can exceed its load capacity depending on the EAF oxidizing slag aggregate content in fine and course aggregate. The amount a load per vehicle should therefore be determined referring to the bulk density test data of the concrete.

6.3 Ready-mixed concrete

When using EAF oxidizing slag aggregate for ready-mixed concrete, JIS A 5308 shall as a rule be observed.

[Commentary]

Ready-mixed concrete made using EAF oxidizing slag aggregate conforming to JIS A 5011-4 is treated similarly to normal aggregate concrete in JIS A 5308 (Ready-mixed concrete). EAF oxidizing slag aggregate to be used for ready-mixed concrete is required to be shipped directly from a JIS-accredited plant to the ready-mixed concrete plant from the aspect of preventing inclusion of EAF reducing slag.

CHAPTER 7 CONCRETING WORK

7.1 General

(1) Construction of a concrete structure using EAF oxidizing slag aggregate shall as a rule comply with the construction planning.

(2) An engineer having sufficient knowledge about the construction of a concrete structure using EAF oxidizing slag aggregate shall be stationed at the job site.

7.2 Conveying within job site, placing and consolidation

7.2.1 General

(1) EAF oxidizing slag aggregate concrete shall be quickly conveyed, promptly placed and sufficiently consolidated.

(2) Conveying, placing and consolidation of EAF oxidizing slag aggregate concrete shall be carried out so as to minimize segregation.

7.2.2 Conveying within job site

(1) The type and number of concrete pumps shall be selected in consideration of the type and quality of EAF oxidizing slag aggregate concrete, pipe diameter, equivalent horizontal pumping distance, pumping load, pumping rate, placing rate, safety against blockage and environmental conditions of the place of construction site.

(2) EAF oxidizing slag aggregate concrete shall be pumped as continuously as possible avoiding stopping. When a long intermission is inevitable, adequate measures shall be taken so that pumping can be resumed without impairing the pumpability and qualities of concrete.

[Commentary]

The maximum pumping load related to a concrete pump, Pmax, should generally be determined by the following equation, and the type of the concrete pump should be selected so that the determined maximum pumping load would be 70% or less of the maximum theoretical pressure under required pumping rate.

$$P_{max} = (\text{pressure loss per m of horizontal pipe}) \times (\text{equivalent horizontal pumping distance})$$

When difficulty is expected for pumping EAF oxidizing slag aggregate concrete, it is desirable to conduct test pumping beforehand using a pipe layout simulating the actual conditions to confirm the pumpability.

When pumping EAF oxidizing slag aggregate concrete, the values specified in the *Standard Specifications, Materials and Construction* for equivalent horizontal pumping distance may be used as they are. When pumping vertically upward, it is advisable to formulate a pumping plan by estimating the equivalent horizontal length for 1 m of a vertical pipe to be about 1 m longer than the value for normal aggregate concrete in consideration of the fact that the bulk density of EAF oxidizing slag aggregate concrete is slightly higher than that of normal aggregate concrete.

7.2.3 Placing

(1) When placing EAF oxidizing slag aggregate concrete in two or more layers, the subsequent layer shall as a rule be placed before the preceding layer begins to set to achieve a monolithic mass. The area of a concreting unit, the concrete supply capacity and the acceptable time lag for placing on consolidated previous layers shall be established to prevent cold joints. The acceptable time lag for placing new layer shall be the values specified in Table 10.3.1 in the *Standard Specifications, Materials and Construction*, as a standard.

(2) When placing over a tall formwork, openings for placing lower layers shall be provided in the formwork, or the discharge end of a vertical chute or piping shall be lowered to near the placing surface. In this case, the height from the placing surface to the discharge end shall be not more than 1.5 m as a standard.

(3) When placing EAF oxidizing slag aggregate concrete continuously in a tall member, such as a wall or column, the depth of a concreting layer and rate of placing shall be adjusted to minimize the effect of bleeding.

7.2.4 Consolidation

(1) EAF oxidizing slag aggregate concrete shall as a rule be consolidated using an internal vibrator.

(2) An internal vibrator shall be used in the following manner as a standard:

  (a) For vibratory consolidation of a concrete layer, the vibrator shall be allowed to penetrate through the layer being vibrated, and into the layer below, by approximately 10 cm.

  (b) The vibrator shall be inserted vertically at uniform spacing less than the effective diameter of action of the vibrator. Spaces between insertions not exceeding 50 cm are generally recommended.

  (c) The vibration time for each insertion shall be 5 to 15 sec.

  (d) The vibrator shall be withdrawn slowly in such a manner that no air pockets are left in the concrete.

(e) Use of vibrators to transport concrete laterally within forms shall not be allowed.

(f) The type, size and number of vibrators shall be selected in consideration of the cross-sectional thickness and area of the member, maximum placing amount per unit time, maximum aggregate size, mixture proportions, particularly the sand-aggregate ratio, slump of concrete, etc., so as to be suitable for consolidating the entire volume of a layer of concrete.

(3) When concrete is to be revibrated, an appropriate time for revibration shall be selected to avoid harmful effects on the concrete.

[Commentary]

When consolidating EAF oxidizing slag aggregate concrete using internal vibrators, it is desirable to exercise sufficient care for the method of consolidation, including limiting the depth of a concreting layer, reducing the spacing between insertions and increasing the number of insertions.

7.3 Finishing

(1) The surfaces of EAF oxidizing slag aggregate concrete shall be finished so that the specified shapes, dimensions and surface conditions can be obtained.

(2) Finishing of the top surfaces of EAF oxidizing slag aggregate concrete shall not be started until the surface water has disappeared or has been removed.

(3) Cracking in EAF oxidizing slag aggregate concrete that occurred after the finishing has completed and before the concrete begins to set shall be removed by tamping or re-finishing.

[Commentary]

Setting of EAF oxidizing slag aggregate concrete tends to retard when compared with that of normal aggregate concrete, delaying the time of finishing. Particular care is therefore necessary when concreting in a cold climate.

7.4 Curing

EAF oxidizing slag aggregate concrete shall be sufficiently cured by maintaining the temperature and humidity necessary for hardening for a certain period after placing to protect the concrete from deleterious action.

7.5 Formwork and shoring

7.5.1 Vertical loads

The bulk density of EAF oxidizing slag aggregate concrete for the design calculation of formwork and shoring shall as a rule be determined from the density and ratio of EAF oxidizing slag aggregate. For reinforced concrete, 0.15 t/m^3 shall be added as the mass of steel reinforcement.

[Commentary]

The density of EAF oxidizing slag aggregate concrete for design calculation of formwork and shoring is required to be determined by calculation, as the EAF slag ratio varies.

7.5.2 Lateral pressure on formwork

The lateral pressure due to EAF oxidizing slag aggregate concrete varies depending on the materials, mixture proportions, placing rate, placing depth, consolidation method and placing temperature of concrete. It is also affected by the type of chemical admixtures, cross-sectional size of the member and reinforcement content. Sufficient investigation of these effects shall therefore be carried out when determining the lateral pressure on formwork.

[Commentary]

The lateral pressure due to EAF oxidizing slag aggregate concrete can be higher than that of normal aggregate concrete, as its density tends to be higher and its setting times tend to be longer than those of normal aggregate concrete depending on the density and EAF slag ratio.

CHAPTER 8 INSPECTION

8.1 Acceptance inspection of aggregate

Aggregate to be used for EAF oxidizing slag aggregate concrete shall be inspected at the time of acceptance as to whether it meets the quality requirements of Chapter 5.

[Commentary]

In the acceptance inspection of EAF oxidizing slag aggregate concrete, conformity to the requirements of JIS A 5011-4 (Electric arc furnace oxidizing slag aggregate) should be confirmed by test data issued by the manufacturer or by testing. For EAF oxidizing slag fine aggregate, the judgment of the saturated surface-dry condition for measuring the density or water absorption may be difficult by the method using a flow cone specified in JIS A 1109 (Methods of test for density and water absorption of fine aggregates). In such a case, it is advisable to employ the "Test methods for density and water absorption of slag aggregate for concrete by measurement of electric resistance" presented in Part III of the present Recommendations.

As stated in Commentary under 5.2.3, normal fine aggregate rejected for grading and chloride content could be used as good-quality fine aggregate for concrete by being blended with EAF oxidizing slag fine aggregate. For this reason, the requirements for grading and chloride content in the *Standard Specifications, Materials and Construction* should not be applied to normal aggregate concrete to be used as part of blended aggregate. Blended EAF oxidizing slag fine aggregate should be judged acceptable, if the inspection results of the blended aggregate conform to 5.2.4 of the present Recommendations.

In the case of blended EAF oxidizing slag fine aggregate, fines 0.15 mm or smaller from normal fine aggregate can include a large percentage of clay or silt. Therefore, fines 0.15 mm or smaller from normal fine aggregate should not exceed 10%, while those from crushed sand should not exceed 15%.

In regard to premixed EAF oxidizing slag aggregate, except for the chloride content it is difficult to judge its conformity to quality requirements by testing. It is therefore necessary to inspect the qualities of each fine aggregate before blending by the test data provided by the manufacturer.

8.2 Acceptance inspection of concrete

Acceptance inspection of EAF oxidizing slag aggregate concrete shall be carried out in accordance with the *Standard Specifications, Materials and Construction.*

[Commentary]

In the inspection of pumpability, it should be confirmed that the maximum pumping load does not exceed 70% of the maximum theoretical pumping pressure under required pumping rate in consideration of safety when the mixture includes blended EAF oxidizing slag fine aggregate with an EAF slag ratio of 30% or more or EAF oxidizing slag coarse aggregate.

8.3 Inspection of concreting work

Inspection of concreting work using EAF oxidizing slag aggregate concrete shall be carried out in accordance with the *Standard Specifications, Materials and Construction.*

CHAPTER 9 CONCRETE REQUIRING SPECIAL CONSIDERATION

9.1 General

When using EAF oxidizing slag aggregate for concrete requiring special consideration, such as precast concrete and pavement concrete, the type and blend ratio of EAF oxidizing slag shall be adequately established so that the resulting concrete meets the quality requirements for the concrete. Proportioning, production and placing shall also be carried out appropriately.

[Commentary]

Precast concrete: Field experience in applying EAF oxidizing slag aggregate to precast concrete includes wave dissipation concrete units making use of the heaviness and hardness of this type of aggregate. Placement tests of full-scale armor units revealed that the fresh and hardened properties were satisfactory, and the units were ascertained to be sound after exposure tests at seashore for 3 years.

Pavement concrete: When applied to pavement concrete, EAF oxidizing slag coarse aggregate generally provides road surfaces with high abrasion resistance, which is a performance essential for pavement concrete, as well as high skid resistance, if the aggregate is exposed. In regard to the flexural strength used for design calculation of concrete pavement, EAF oxidizing slag aggregate concrete is expected to develop a strength equal to or higher than that of normal aggregate concrete having the same water-cement ratio.

9.2 Precast concrete

When using EAF oxidizing slag aggregate for precast concrete, the requirements of the *Standard Specifications, Materials and Construction* shall be observed, while carrying out appropriate investigation to fully develop the performance of the concrete.

[Commentary]

Since the oven-dry density of EAF oxidizing slag aggregate is significantly higher than that of normal aggregate, the density of the resulting concrete becomes significantly high. For this reason, the use of this type of aggregate for retaining walls to resist earth pressure and masonry units and wave dissipation concrete units subjected to buoyancy is advantageous from the aspect of design.

When used for concrete with a low unit water content for the instant form stripping method to produce masonry units, the tendency of EAF oxidizing slag aggregate toward a high unit water content is restricted. The angular particle shapes of EAF oxidizing slag aggregate also tends to reduce the deformation after form stripping by this method.

9.3 Pavement concrete

When using EAF oxidizing slag aggregate concrete for concrete pavement, the requirements of the *Standard Specifications 2002, Paving* shall be observed, while carrying out appropriate investigation to fully develop the performance of concrete.

[Commentary]

Since unreinforced stiff-consistency concrete is generally used for pavement, it is expected to have an effect of restricting the tendency of EAF oxidizing slag aggregate concrete toward a high unit water content. EAF oxidizing slag aggregate may develop properties suitable for pavement concrete, such as small length changes due to drying shrinkage, depending on the EAF oxidizing slag aggregate content. Applications to make use of these properties should be explored.

The hardness and surface irregularity of EAF oxidizing slag coarse aggregate are effective in increasing the skid resistance. Exposed-aggregate finish is recommended for making the most of the high skid resistance of EAF oxidizing slag coarse aggregate. The high abrasion resistance brought about by EAF oxidizing slag coarse aggregate is also suitable for concrete pavement in a cold climate exposed to tire chain abrasion.

The surface mortar thickness of roller-compacted concrete pavement is small, due to compaction with vibratory rollers or tire rollers. This method is therefore effective in developing the high skid resistance and abrasion resistance of EAF oxidizing slag coarse aggregate.

CHAPTER 10 GENERAL RULES FOR STRACTURAL DESIGN

10.1 General

(1) This chapter provides general basic requirements for structures made of EAF oxidizing slag aggregate concrete.
(2) The general requirements for design stipulated in this chapter shall as a rule be applied to EAF oxidizing slag aggregate concrete with a specified strength of up to 60 N/mm^3.
(3) As to matters not specified in this chapter, the *Standard Specifications, Structural Performance Verification* shall apply. In regard to seismic design, the *Standard Specifications 2002, Seismic Performance Verification* shall apply.

[Commentary]

The basic concept of design of structures made of EAF oxidizing slag aggregate concrete is similar to that of normal aggregate concrete. When concrete is made using EAF oxidizing slag fine aggregate designated as class N at an EAF slag ratio of less than 30% in combination with coarse aggregate entirely consisting of gravel or crushed stone, it can be designed similarly to normal aggregate concrete.

However, in the case where the EAF slag ratio in fine aggregate is 30% or more or where the coarse aggregate consists of EAF oxidizing slag aggregate, design values different from those for normal aggregate concrete may have to be used. Accordingly, this chapter primarily describes the design values for concrete made using EAF oxidizing slag aggregate concrete. The *Standard Specifications, Structural Performance Verification* should be referred to for design values not provided in this chapter.

It should be noted that this chapter covers EAF oxidizing slag aggregate concrete with a compressive strength of up to 60 N/mm^2, for which the quality has been sufficiently confirmed by field experience and reference data.

10.2 Design values of concrete

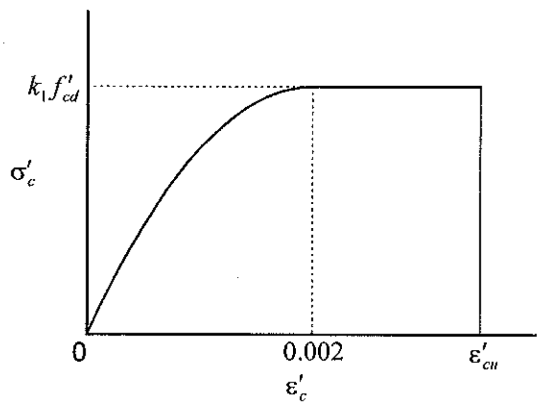
10.2.1 Strength

The characteristic values of the bond strength, bearing capacity and fatigue strength of EAF oxidizing slag aggregate concrete shall be established based on test strengths determined from appropriate tests.

10.2.2 Stress-strain curve

(1) An adequate shape of the stress-strain curve shall be assumed for EAF oxidizing slag aggregate concrete according to the purpose of analysis.

(2) In the analysis of the ultimate limit state of section failure of a concrete member with a compressive strength of 60 N/mm^2 or less subjected to bending moment and both bending moment and axial force, a modeled stress-strain curve shown in Fig. 10.1 may be used.



$$k_1 = 1 - 0.003 f'_{ck} \quad \leq 0.85$$

$$\varepsilon'_{cu} = \frac{155 - f'_{ck}}{30000} \quad 0.0025 \leq \varepsilon'_{cu} \leq 0.0035$$

where the unit of f'_{ck} is N/mm^2

The stress-strain equation for the curved part:

$$\sigma'_c = k_1 f'_{cd} \times \frac{\varepsilon'_c}{0.002} \times \left(2 - \frac{\varepsilon'_c}{0.002}\right)$$

Fig. 10.1 Stress-strain curve of EAF oxidizing slag aggregate concrete

[Commentary]

Due to the hardness of aggregate, the strain of EAF oxidizing slag aggregate concrete generally tends to be smaller than that of normal aggregate concrete under the same stress. However, the difference of the stress-strain curve scarcely affects the calculated ultimate capacity in certain cases, such as that of bar-shaped members subjected to bending moment or both bending moment and axial force. In such a case, the modeled curve shown in Fig. 10.1 may be used as the stress-strain curve.

10.2.3 Elastic modulus

The elastic modulus of EAF oxidizing slag aggregate concrete may be assumed to be the values given in Table 10.1 unless determined by testing.

Table 10.1 Elastic modulus of EAF oxidizing slag aggregate concrete

f'_{ck} (N/mm^2)	18	24	30	40	50	60
E_c (kN/mm^2)	22	25	28	31	33	35

[Commentary]

Care should be exercised when using the same elastic modulus as normal aggregate concrete for considering the thermal stress resulting from hydration heat of cement, as the calculated stress is lower than the actual value. Tests should be conducted to determine the elastic modulus when the largeness of the elastic modulus is utilized or when the thermal stress is of concern.

10.2.4 Thermal properties

(1) The thermal properties of EAF oxidizing slag aggregate concrete shall as a rule be established based on experiments or past data.

(2) The thermal expansion coefficient of EAF oxidizing slag aggregate concrete may generally be assumed to be 10×10^{-6}/°C

[Commentary]

Due to the high density of EAF oxidizing slag aggregate, the thermal capacity of EAF oxidizing slag aggregate concrete tends to be higher than that of normal aggregate concrete, while its ultimate adiabatic temperature rise tends to be smaller. However, this may not be univocally advantageous for thermal stress, as density also affects the thermal diffusion coefficient. Therefore, the thermal properties of EAF oxidizing slag aggregate concrete may generally be assumed to be the same as that of normal aggregate concrete, but it should be confirmed by testing when the thermal stress is of concern.

10.2.5 Shrinkage

The shrinkage strain of EAF oxidizing slag aggregate concrete may be assumed to be the values given in 3.2 of the *Standard Specifications, Structural Performance Verification.*

10.2.6 Bulk density

(1) The actual bulk density of EAF oxidizing slag aggregate concrete shall as a rule be used for calculation of its dead load.

(2) When the actual bulk density of EAF oxidizing slag aggregate concrete is unknown, the values given in Table 10.2 may be used as the bulk density, provided EAF oxidizing slag aggregate designated as class N is used for the concrete.

Table 10.2 Bulk density of EAF oxidizing slag aggregate concrete (kg/m^3)

EAF slag volume ratio of fine aggregate / EAF slag volume ratio of coarse aggregate	0	30	50
0	-	2400	2500
100	2800	2900	-

[Commentary]

(1) The bulk density of EAF oxidizing slag aggregate concrete is greater than that of normal aggregate concrete and depends on the brand and content of EAF oxidizing slag aggregate. For this reason, the use of actual density is required for design calculation.

(2) Table 10.2 gives approximate values of bulk density for the levels of EAF slag ratios frequently adopted in concrete made using EAF oxidizing slag aggregate designated as class N by oven-dry density. When the actual bulk density is unknown, the values in the table may be used. However, actual bulk density should be used when using aggregate designated as class H or when the EAF oxidizing slag aggregate content exceeds the range given in the table.

PART II PROPORTIONING MANUAL

1. Scope

(1) This manual describes the points of proportioning concrete to be used for concreting work based on the Recommendations for Design and Construction of Concrete Structures Made Using Electric Arc Furnace Oxidizing Slag Aggregate.

(2) The proportioning methods and points of note described in this manual pertain to concrete made using electric arc furnace (EAF) oxidizing slag aggregate for general concrete structures and are intended to achieve the performance required for such concrete based on field experience.

[Commentary]

This manual assumes the case where the EAF oxidizing slag aggregates are designated as density class N and the coarse aggregate singly consists of either EAF oxidizing slag aggregate or normal aggregate, such as crushed stone, whereas the fine aggregate consists of a combination of normal fine aggregate and EAF oxidizing slag fine aggregate, with EAF oxidizing slag fine aggregate accounting for less than 50% of the total absolute volume of fine aggregate.

In the proportioning of concrete containing EAF oxidizing slag aggregate, it is particularly important to ensure plasticity while fresh without segregation. Care should also be exercised in regard to the high bulk density of concrete.

2. Combinations of aggregates

(1) Proportioning of concrete made using normal coarse aggregate and blended EAF oxidizing slag aggregate with an EAF slag ratio of less than 30% can generally be regarded as similar to proportioning of normal aggregate concrete.

(2) It is advisable to give consideration to the matters provided in this Manual when proportioning concrete made using normal coarse aggregate and blended EAF oxidizing slag fine aggregate with

an EAF slag ratio of 30 to 50% and concrete made using EAF oxidizing slag coarse aggregate and blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30%.

(3) Concrete other than (1) and (2) should be proportioned while confirming the attainment of the required placement-related performance and performance after hardening by testing or other means.

[Commentary]

(1) When the coarse aggregate entirely consists of crushed stone or gravel and the EAF slag ratio of the blended EAF oxidizing slag fine aggregate is less than 30%, no excessive bleeding occurs, while the increase in the bulk density of the resulting concrete is negligible. The concrete can therefore be proportioned similarly to normal aggregate concrete.

(2) When the coarse aggregate entirely consists of crushed stone or gravel and the EAF slag ratio of the blended EAF oxidizing slag fine aggregate is between 30 and 50%, the concrete can be proportioned to provide placement-related performance and qualities comparable to those of normal aggregate concrete by controlling the unit water content necessary for achieving the required slump. An air-entraining and water-reducing admixture or other admixtures should be used for such control.

When EAF oxidizing slag coarse aggregate is to be used, it should be used singly without being blended with other types of coarse aggregate as a standard. Concrete made using EAF oxidizing slag coarse aggregate and blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30% should be proportioned with consideration to the workability. As the EAF slag ratio of blended EAF oxidizing slag fine aggregate increases, and when EAF oxidizing slag coarse aggregate is used, it becomes important to consider the use of an air-entraining and high-range water-reducing admixture, etc., to reduce the unit water content, as well as the use of mineral admixture, such as lime stone powder, to control the amount of bleeding water.

(3) An EAF slag ratio of over 50% in blended EAF oxidizing slag fine aggregate, particularly in combination with EAF oxidizing slag coarse aggregate, is applicable to concrete for structures and products for which a high bulk density is advantageous. In this case, a minimum practicable slump of concrete should be selected according to the purpose of use, while confirming by testing beforehand the achievement of the placement-related performance and performance required for hardened concrete.

3. Strength for mixture proportioning

(1) The strength for mixture proportioning of concrete should be established in consideration of the specified strength and the quality fluctuation of concrete at the job site.

(2) The strength for mixture proportioning of concrete, f'_{cr}, should generally be established so that the probability of failing to achieve the specified strength, f'_{ck}, is expected to be not more than 5% of the population of all compression test values on the job site.

[Commentary]

When using blended EAF oxidizing slag fine aggregate with an EAF slag ratio of 30% or more and less than 50%, the multiplying factor of design strength for determining the strength for mixture proportioning should be slightly greater, as the selected high air content may increase the fluctuation of strength. When using blended EAF oxidizing slag fine aggregate with an EAF slag ratio exceeding 50% or when it is additionally combined with EAF oxidizing slag coarse aggregate, the multiplying factor should be adequately established by investigating test data and field experience, as the qualities of the resulting fresh concrete are prone to large fluctuation.

4. Maximum aggregate size

The maximum aggregate size should be in accordance with Appendix I (Proportioning methods for concrete), Section 4, of the *Standard Specifications for Design and Construction of Concrete Structures* (hereafter referred to as the Standard Specifications), *Materials and Construction.*

5. Slump of concrete

(1) The as-mixed slump of EAF oxidizing slag aggregate concrete should be established in consideration of the slump loss during transportation from the concrete plant to the job site and conveyance within the job site to achieve the slump at the time of placing specified in Section 5.2 (3) of the *Standard Specifications, Materials and Construction.*

(2) Slump testing should comply with JIS A 1101.

[Commentary]

The slump loss of EAF oxidizing slag aggregate concrete during transportation from the plant to the job site tends to be greater than that of normal aggregate concrete. During a transportation time of around 30 min, the slump loss of normal aggregate concrete is generally limited to 1 to 2 cm, but that of EAF oxidizing slag aggregate concrete tends to be greater at 3 to 4 cm. On the other hand, the slump loss during conveyance by pumping within the job site may generally be regarded as similar to that of normal aggregate concrete, as the low water absorption of EAF oxidizing slag aggregate stabilizes the slump.

6. Air content of air-entrained concrete

(1) Concrete containing EAF oxidizing slag aggregate should as a rule be made as air-entrained concrete.

(2) The as-mixed air content should be established in consideration of the maximum aggregate size and losses during transportation from the plant to the job site and within the job site.

(3) The as-mixed air content should generally be between 5 and 7% by volume of concrete as a standard depending on the maximum aggregate size.

(4) The as-mixed air content of marine concrete should be the values given in Table 6.1 as a standard.

Table 6.1 Standard air content of marine concrete (%)

Environmental conditions and classes		Maximum aggregate size (mm)	
		20	40
With risk of freezing and thawing action	(a) Marine atmosphere	6.0	5.5
	(b) Splash zone	7.0	6.5
No risk of freezing and thawing action		5.0	5.0

(5) The air content testing should comply with JIS A 1116, JIS A 1118 or JIS A 1128.

[Commentary]

(1) and (2) Proper air entrainment in EAF oxidizing slag aggregate concrete reduces the unit water content necessary for achieving the required slump while controlling the amount of bleeding water, thereby imparting plastic properties to concrete.

Particularly when pumped, concrete containing EAF oxidizing slag aggregate is prone to blockage at tapers and bends. However, an increased air content of concrete is also expected to contribute to achievement of the pumpability specified in Section 4.3 of the Recommendations.

(3) Concrete containing EAF oxidizing slag aggregate tends to entrap air during mixing, particularly with a high water-cement ratio. For this reason, air content values higher than normal aggregate concrete by 1 percentage point were adopted as a standard.

Generally speaking, the as-mixed air content of concrete made using EAF oxidizing slag fine aggregate in combination with normal coarse aggregate may be set at 5 to 6% and 4 to 5% for a maximum aggregate size of 20 and 40 mm, respectively.

(4) An air content 1 percentage point higher than normal concrete was also adopted as a standard for marine concrete made using EAF oxidizing slag aggregate, since it is important to make such concrete plastic to inhibit the bleeding-induced deterioration, while preventing placement-related defects.

(5) Significant surface irregularities due to air bubbles are found on certain brands of EAF oxidizing slag aggregate. It is therefore necessary to determine beforehand an appropriate correction factor when adopting the test method specified in JIS A 1128 (Method of test for air content of fresh concrete by pressure method).

7. Water-cement ratio

(1) The water-cement ratio (*W/C*) of concrete made using EAF oxidizing slag aggregate should as a rule be not more than 65%.

(2) The *W/C* should be established in consideration of the mechanical performance, durability, watertightness and other performances, and the minimum among the values determined from these requirements should be selected.

(3) When *W/C* is to be established based on the compressive strength of concrete, it should be established as follows:

(a) The relationship between compressive strength and *W/C* should as a rule be determined by testing. The test age should be 28 days.

(b) The *W/C* to be used for mixture proportioning should be the inverse of the cement-water ratio (*C/W*) corresponding to the strength for mixture proportioning, f'_{cr}, in the relational expression between *C/W* and compressive strength, f'_c, at the reference age.

(4) When establishing *W/C* based on the resistance to freezing and thawing, the *W/C* should be not more than the values given in Table 7.1. When a good quality mineral admixture is properly used, the total of the mass of cement and the mass of the mineral admixture may be assumed to be the binder content.

Table 7.1 Maximum *W/C* of air-entrained concrete when establishing *W/C* based on the required freeze-thaw resistance (%)

Exposure \ Climatic condition / Cross section	Fierce climatic condition; frequently repeated freezing and thawing		Mild climatic condition; temperatures rarely drop below freezing point	
	Thin[2)]	Normal	Thin[2)]	Normal
(1) Continuously or frequently saturated with water[1)]	55	60	55	65
(2) Normal exposure conditions not included in (1)	60	65	60	65

1) Parts of waterways, water tanks, abutments, bridge piers, retaining walls, tunnel lining, etc., that are located near water surfaces and saturated with water. Parts of beams, slabs, etc., of these and other structures saturated with snowmelt, running water, splashes, etc., though located away from water surfaces.

2) Parts of structures with a cross-sectional thickness of up to around 20 cm, etc.

(5) When establishing *W/C* based on the required resistance of concrete to chemical attack, the values should be established as given below referring to Table 7.2. When a good quality mineral admixture is properly used, the total of the mass of cement and the mass of the mineral admixture may be assumed to be the binder content.

(a) For concrete to be in contact with soil or water containing sulfate at an equivalent SO_4^{2-} concentration of 0.2% or more, the *W/C* should be not more than the values given in Table 7.2 (c).

(b) For concrete to be exposed to deicers, the *W/C* should be not more than the values given in Table 7.2 (b).

(6) For marine concrete, the maximum *W/C* determined from the required durability should be the values given in Table 7.2 as a standard. For unreinforced air-entrained concrete, the *W/C* (water-binder ratio) determined from the required durability may be assumed to be the values given in Table 7.2 with an addition of around 10 %.

Table 7.2 Maximum *W/C* of air-entrained concrete determined from the required durability (%)

Environmental class \ Placement conditions	General in-situ placing	Precast concrete products or when quality equal to higher than precast products is assured
(a) Marine atmosphere	40	45
(b) Splash zone	40	40
(c) Submerged in seawater	45	45

(7) For concrete required to be watertight, the maximum *W/C* (water-binder ratio) determined from the required watertightness should be 50%.

[Commentary]

(1), (2) and (3) The compressive strength of concrete made using EAF oxidizing slag aggregate tends to be lower at early ages than that of normal aggregate concrete with the same *W/C* and air content, but becomes equal or higher at later ages.

(4) When blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30% is used in combination with normal coarse aggregate, the resistance to frost damage of the resulting EAF oxidizing slag aggregate concrete may be regarded as comparable to that of normal aggregate concrete. On the other hand, the resistance to frost damage may tend to be slightly lower when blended EAF oxidizing slag fine aggregate with an EAF slag ratio of 30 to 50% is used in combination with normal coarse aggregate and when blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30% is used in combination with EAF oxidizing slag coarse aggregate. However, resistance to frost damage comparable to normal aggregate with the same *W/C* can be ensured by properly using an air-entraining and water-reducing admixture, etc., to control the amount of bleeding water and by establishing the air content at a slightly high level.

When the type, quality and content of EAF oxidizing slag aggregate, as well as other conditions including proportioning conditions, hamper the amount of bleeding water to remain below 0.4 cm^3/cm^2, the resistance of the concrete to repeated freezing and thawing can be low. It is vital for such a mixture to reduce the water-binder ratio.

(5) There have not been sufficient data regarding the performance of EAF oxidizing slag aggregate concrete related to chemical attack. *W/C* values by 5 percentage points smaller than those of normal concrete were adopted, to be on the safe side, for *W/C* determined from the required resistance to chemical attack, as this type of concrete tends to generate a large amount of bleeding water.

(6) and (7) The maximum *W/C* of air-entrained concrete determined from the required durability of concrete made using blended EAF oxidizing slag fine aggregate with an EAF slag ratio of less than 30% may be on the same level as those specified in the *Standard Specification, Materials and Construction.* However, in consideration of safety related to the durability of structures under fierce environmental conditions, values 5 percentage points lower than normal are adopted in Table 7.2 for the case of an EAF slag ratio of 30 to 50% and the case of using EAF oxidizing slag coarse aggregate.

Also, in consideration of safety against the tendency of EAF oxidizing slag aggregate concrete toward a large amount of bleeding water, a value below 50% was adopted for the *W/C* determined from the required watertightness.

8. Unit water content

(1) The unit water content should be determined by testing to be the minimum possible within the workable range.
(2) The unit water content of EAF oxidizing slag aggregate concrete should as a rule be not more than 175 kg/m^3.

[Commentary]

The amount of bleeding water of EAF oxidizing slag aggregate concrete tends to increase as the EAF slag ratio of the blended EAF oxidizing slag fine aggregate increases and when EAF oxidizing slag coarse aggregate is used. Also, if the unit water content is increased to increase the slump, then the resulting concrete becomes prone to subsidence of coarse aggregate. It is therefore crucial for producing uniform concrete to reduce the unit water content using an air-entraining and high-range water-reducing admixture, air-entraining and water-reducing admixture, etc.

9. Sand-aggregate ratio

(1) The sand-aggregate ratio should be determined by testing to achieve the minimum possible unit

water content while maintaining the required workability.

(2) The volumetric coarse aggregate content may be established instead of the sand-aggregate ratio. In this case as well, the volumetric coarse aggregate content should be determined by testing to achieve the minimum possible unit water content while maintaining the required workability.

[Commentary]

When using fine aggregate with a low solid volume percentage, such as EAF oxidizing slag fine aggregate having angular particles, a low fineness modulus of fine aggregate tends to lead to a low sand-aggregate ratio.

10. Unit content of admixture

The admixture content should be established to achieve the performance required for concrete.

[Commentary]

Similarly to other slag aggregates, the use of EAF oxidizing slag aggregate tends to increase the unit water content of concrete. It is therefore essential to use a good quality air-entraining and water-reducing admixture to minimize the unit water content. When the risk of a large amount of bleeding water is assumed, it is effective to use such mineral admixtures as lime stone powder and ground granulated blast-furnace slag.

11. Unit cement content

The cement content of EAF oxidizing slag aggregate concrete should as a rule be established from the unit water content and *W/C*.

[Commentary]

The cement content determined from the unit water content and *W/C* tends to increase, as this proportioning manual recommends that the as-mixed slump be determined in consideration of the slump loss during transportation from the plant to the job site and pumping within the job site. Increasing the viscosity of fresh concrete by an increase in the powder content is desirable for EAF oxidizing slag aggregate concrete, which tends to be rough. However, care should also be exercised for disadvantages brought about by the resulting increase in the binder content.

The cement content should be minimized to control temperature cracking of massive concrete. However, the ultimate adiabatic temperature rise of EAF oxidizing slag aggregate concrete tends to be smaller than that of normal aggregate concrete with similar proportioning conditions, due to the high thermal capacity of concrete. Laboratory tests have revealed that the ultimate adiabatic temperature rise of EAF oxidizing slag aggregate concrete is about 3°C lower than normal aggregate concrete when the fine and coarse aggregate entirely consists of EAF oxidizing slag.

12. Chloride content limit

The total chloride ion content of concrete at the time of mixing should as a rule be not more than 0.30 kg/m^3.

[Commentary]

No seawater is used for cooling molten slag for the production of EAF oxidizing slag aggregate. Precautions for the total chloride ion content of concrete may therefore be considered similarly to those for normal aggregate concrete.

13. Form for expressing mixture proportions

(1) The form for expressing the mixture proportions should be as given in Table 13.1.

Table 13.1 Form for expressing specified mixture proportions

<table>
<tr><td colspan="4">Maximum aggregate size (mm)</td><td colspan="2"></td></tr>
<tr><td colspan="4">Slump (cm)</td><td colspan="2"></td></tr>
<tr><td colspan="4">Air content (%)</td><td colspan="2"></td></tr>
<tr><td colspan="4">W/C (%)[1]</td><td colspan="2"></td></tr>
<tr><td colspan="4">Sand-aggregate ratio (%)</td><td colspan="2"></td></tr>
<tr><td rowspan="8">Unit content (kg/m^3)</td><td colspan="3">Water, W</td><td colspan="2"></td></tr>
<tr><td colspan="3">Cement, C</td><td colspan="2"></td></tr>
<tr><td colspan="3">Mineral admixture, F</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Fine aggregate[2], S</td><td colspan="2">Normal sand</td><td></td><td rowspan="2">(%)</td></tr>
<tr><td colspan="2">EAF oxidizing slag</td><td></td></tr>
<tr><td rowspan="2">Coarse aggregate[3], G</td><td rowspan="2"></td><td>( )–( ) mm</td><td colspan="2"></td></tr>
<tr><td>( )–( ) mm</td><td colspan="2"></td></tr>
<tr><td colspan="3">Chemical admixture[4]</td><td colspan="2"></td></tr>
</table>

1) When using a mineral admixture having pozzolanic reactivity or latent hydraulic properties, *W/C* is replaced with water-binder ratio.

2) Enter the normal fine aggregate content and EAF oxidizing slag fine aggregate content individually in the boxes on the left. Enter the blended EAF oxidizing slag fine aggregate content in the box on the right. Enter the EAF slag ratio in the parenthesis.

3) Enter the type of the coarse aggregate in the box on the left.

4) Indicate the chemical admixture dosage in ml/m^3 or g/m^3. Enter the undiluted value.

(2) In the specified mixture proportions, fine aggregate and coarse aggregate are defined as entirely passing a 5-mm sieve and entirely retained on a 5-mm sieve, respectively. Both should be expressed in the saturated surface-dry condition.

(3) When modifying the specified proportions into job mixture proportions, consideration should be given to the moisture condition of aggregate, the amount of fine aggregate retained on a 5-mm sieve, the amount of coarse aggregate passing a 5-mm sieve and the amount of water used for diluting the chemical admixture.

[Commentary]

When EAF oxidizing slag fine aggregate and normal fine aggregate are to be mixed at the time of concrete mixing, the content of each aggregate, total content of both and EAF slag ratio should be indicated. When premixed EAF oxidizing slag fine aggregate is to be used, its content and EAF slag ratio are required to be indicated.

The coarse aggregate may be crushed stone, etc., or EAF oxidizing slag coarse aggregate. The type of the coarse aggregate to be used should be indicated in the box on the left side.

PART III JSCE STANDARD

TEST METHOD FOR DENSITY AND WATER ABSORPTION OF SLAG FINE AGGREGATE FOR CONCRETE BY MEASUREMENT OF ELECTRIC RESISTANCE (JSCE-C506-2003)

1. Scope

This standard covers test methods for density and water absorption of slag fine aggregate for concrete for which judgment of saturated surface-dry condition is expected to be difficult by the method using a flow cone described in JIS A 1109.

Remark: Slag aggregates for concrete, such as blast-furnace slag fine aggregate, ferronickel slag fine aggregate, copper slag fine aggregate and electric arc furnace oxidizing slag fine aggregate, include those having particles of various shapes ranging from spherical to angular or with extraordinarily unbalanced grading. For this reason, judgment of saturated surface-dry condition using a flow cone in accordance with JIS A 1109 is difficult in many cases. The present test methods are useful for determining the density and water absorption of fine aggregate having unusual shapes and grading.

2. Standards cited

The following standards form a part of this standard by being cited to in this standard. The latest editions of these reference standards shall be used.

JIS A 1109	Methods of test for density and water absorption of fine aggregate
JIS K 8150	Sodium chloride
JIS Z 1712	Oriented polypropylene films for packaging
JIS Z 1714	Biaxially oriented nylon films for packaging
JIS A 1125	Methods of test for total moisture content of aggregates and surface moisture in aggregates by drying

3. Apparatus and Reagent

3.1 Balance

A balance having a capacity of 2 kg or more and sensitive to 0.1 g or better shall be used.

3.2 Pycnometer

The pycnometer to be used for density testing shall be a marked or graduated glass container or a glass container with a ground (frosted) top edge. It shall be such that the fine aggregate test sample can be readily introduced and the volume content can be reproduced within ± 0.1%. The volume of the container filled to the calibration mark shall be at least 1.5 times but not greater than 3 times the space required to accommodate the test sample.

Reference: A calibration capacity of 500 ml is normally used.

3.3 Analogue tester

An analog tester for measuring the electric resistance of fine aggregate shall be an analogue type tester with a capacity of approximately 3000 kΩ[(1)].

Note (1): An analogue tester is specified, as it provides stable readings without excessive sensitivity to the fluctuation of resistance values.

3.4 Container for measuring electric resistance

The container for measuring the electric resistance of fine aggregate shall be fabricated using a non-absorbent insulating material. It shall be an open-top box with inside dimensions of 40 by 40 by 100 mm as shown in Fig. 1. A 40 by 40-mm copper plate electrode shall be placed on each end of the box.

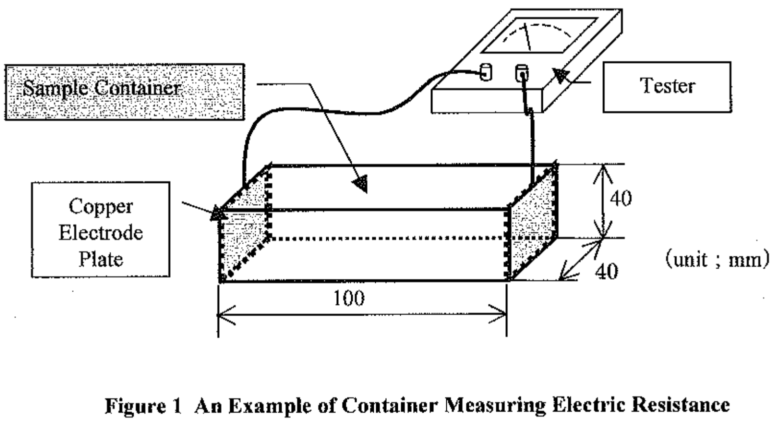


Figure 1 An Example of Container Measuring Electric Resistance

3.5 Tamper

A mild steel tamper weighing 1000 ± 5 g and having a flat square tamping face 35 ± 1 mm each side shall be used.

3.6 Sodium chloride reagent

A guaranteed grade sodium chloride reagent conforming to JIS K 8150 shall be used(2).

Note (2): Sodium chloride is added to stabilize the readings while measuring the electric resistance of fine aggregate test sample.

3.7 Container for agitation

A container for agitation shall be used for mixing fine aggregate with the sodium chloride reagent. It shall be a highly airtight container made of non-absorbent material and of a sufficient size to allow easy mixing.

Remark: A highly airtight container into which the fine aggregate test sample can be readily introduced is desirable. Recommended containers include a 500-ml wide-mouthed glass reagent bottle with ground-in stopper and an airtight container made of polypropylene or polyethylene.

3.8 Moisture-retaining film

The moisture-retaining film for covering the container for measuring electric resistance after filling the test sample in the container shall conform to JIS Z 1712 or JIS Z 1714.

3.9 Dryer

The dryer shall have an exhaust slot and shall be capable of maintaining a temperature of 105 ± 5°C.

4. Sampling and preparation

4.1 Sampling

Sampling shall be carried out as follows:

(a)A sample representing the material shall be obtained and reduced to nearly the required amount by quartering or using a sample splitter. The mass of a reduced sample shall be approximately 15 kg.

(b)The sample shall be allowed to absorb water for 24 hours. The water temperature shall be maintained at 20 ± 5°C for at least 20 hours during absorption.

4.2 Preparation of test specimen

Test specimens shall be prepared as follows:

a) Spread the sample thinly on a flat surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying.

b) Prepare test specimens for measuring the water absorption by obtaining at least 1200 g each of test specimens to be subjected to measurement of the moisture content and electric resistance. Obtain the specimens at three or more arbitrary levels of water content while free surface water is present and three or more arbitrary levels after the surface water is no longer present during the process of drying.

Remark: It is necessary that a test specimen with a water content level close to an air-dry condition is included.

c) Prepare a test specimen of at least 2.0 kg for density testing with an arbitrary level of water content while surface moisture is present and keep the water content unchanged during storage.

5. Procedure

5.1 Water absorption

The procedure of water absorption testing shall be as follows:

(a)Quarter the test specimen adjusted to an arbitrary level of water content to obtain approximately 300 g and determine the mass (m) to 0.1 g. Then dry the specimen at 105 ± 5°C to constant mass, allow to cool to room temperature in a desiccator and determine the mass (m_D) to 0.1 g.

(b)Obtain another quarter of approximately 300 g of the same moisture condition into the container for agitating, add approximately 5 g of NaCl reagent, mix the contents by shaking the container vigorously for approximately 1 min and allow to stand for approximately 3 min.

(c)Shake the sample vigorously again to thoroughly mix the test specimen before filling into the container for measuring the electric resistance. Fill the test specimen into the container in three layers to the top edge. Compact each layer with a tamper by applying 15 strokes for each layer. Cover the top surface of the filled specimen with moisture-retaining film(3).

Note (3): This is to protect the specimen of an arbitrary level of moisture content from drying during resistance measurement.

(d)Measure the electric resistance of the test specimen (R_i) with a tester.

(e)Repeat the procedure from (a) to (d) for each of the specimens of at least six arbitrary levels of moisture content prepared in 4.2 (b).

5.2 Density

The density testing shall be carried out as follows:

(a)Quarter the specimen in 4.2 (c) into portions of approximately 500 g and determine the mass of each portion (m_l) to 0.1 g.

(b)Use two portions for density testing. Use the other two portions for measuring the water content of the specimen (Z) by the method described in JIS A 1125.

(c)Fill a pycnometer with water to the calibration mark, and determine the mass of the pycnometer containing water (m_Z) to 0.1 g(4).

(d)Empty the pycnometer and fill it with a test specimen for density testing in (a) to the calibration mark.

(e)Tilt and roll the pycnometer on a flat surface to eliminate all air bubbles. Then immerse the pycnometer in a water tank with a temperature of 20 ± 5°C(5).

(f)After immersing the pycnometer in the water tank for approximately 1 h, add water to the calibration mark and determine the mass (m_3, total mass of the container, specimen and water) to 0.1 g(5). The difference between the temperatures of water in the pycnometer at the first and second measurements shall not exceed 1°C.

Note (4): When using a container with a ground (frosted) top edge, determine the mass with the cover or a frosted glass plate placed on the container. Measure the water temperature at the time of weighing.

Note (5): When using a container with a ground (frosted) top edge, the process of immersing in a water tank at 20 ± 5°C may be omitted in the procedure from (d) to (f).

5.3 Number of tests

Density and water absorption testing shall be carried out twice using samples simultaneously obtained.

6. Calculation

6.1 Water content at an arbitrary moisture level and water absorption

The water content at an arbitrary moisture level and the water absorption of a test specimen shall be calculated as follows:

(a)Calculate the water content of a test specimen prepared to an arbitrary moisture level (Z_i) by the following equation and round off to the nearest 0.01:

$$Z_i = \frac{m - m_D}{m_D} \times 100$$

where, Z_i = water content (%), m = mass of test specimen before drying (g), m_D = mass of test specimen after drying (g)

(b)Plot three or more electric resistance values in the surface-wet range and three or more values in the surface-dry range on a diagram in which the x axis (arithmetic scale) represents water content (Z_i) and the y axis (common logarithmic scale(6)) represents electric resistance (R_i). Approximate the relationship between the electric resistance and water content to a straight line for each of the surface-wet and surface-dry ranges.

Note (6): For samples with a significantly high fines content, an arithmetic scale for electric resistance may be easier for approximation to a straight line.

(c)Determine the water content corresponding to the intersection point of these two straight lines as the water absorption in the saturated surface-dry condition (Q). Round off the calculation result to the nearest 0.01.

Reference: This is because the moisture condition immediately before the upsurge in the electric resistance as the sample condition changes from wet to dry is assumed to be the saturated surface-dry condition.

(d)The average of two test values shall be taken as the water absorption.

6.2 Density

The density shall be calculated as follows:

(a)The density of a sample in the saturated surface-dry and absolutely dry conditions shall be calculated by the following equations and rounded off to the nearest 0.01.

$$d_S = \frac{m_s}{V_s} = \frac{\rho_W \cdot (1+Q/100) \cdot m_1}{(1+Q/100) \cdot m_1 - (1+Z/100) \cdot (m_3 - m_2)}$$

$$d_D = \frac{d_S}{1+Q}$$

where, d_S = density in saturated surface-dry condition (g/cm^3)

m_1 = mass of sample in wet condition (g)

m_2 = mass of pycnometer containing water to calibration mark (g)

m_3 = mass of pycnometer containing sample and water after eliminating all air bubbles entrapped between particles (g)

m_S = mass of sample in saturated surface-dry condition in mass m_1 (g)

$$m_S = \frac{(1+Q/100) \cdot m_1}{1+Z/100}$$

V_S = apparent volume of sample in wet condition with a mass of m_1 (cm^3)

$$V_S = \frac{(1+Z/100) \cdot (m_2 - m_3) + (1+Q/100) \cdot m_1}{\rho_W \cdot (1+Z/100)}$$

ρ_W = density of water at test temperature(7) (g/cm^3)

Note (7): The densities of purified water at 15, 20 and 25°C are 0.9991, 0.9982 and 0.9970 g/cm^3, respectively.

Q = water absorption obtained by water absorption testing (%)

Z = water content of sample used for density testing (%)

d_D = density in oven-dry condition (g/cm^3)

(b)The average of the two test values shall be taken as the density.

7. Precision

Individual test values shall not differ from the average by more than 0.01 g/cm^3 and 0.05% for density and water absorption, respectively.

8. Report

8.1 Mandatory report items

Report shall include the following:

(a)Type, appearance and source of aggregate

(b)Date and time of sampling

(c)Density in saturated surface-dry condition and oven-dry condition (g/cm^3)

(d)Water absorption (%)

(e)Temperature of water used in the test

8.2 Non-mandatory report items

The following items shall be included in the report as required:

(a)Diagram of relationship between electric resistance and water content used in water absorption testing

(b)Electric resistance, water content and straight line approximation equations at high and low moisture contents

(c)Moisture content of sample in density testing (%)

(d)Mass of sample in saturated surface-dry condition in mass m_1 (g)

(e)Apparent volume of sample in mass m_1 in saturated surface-dry condition (cm^3)