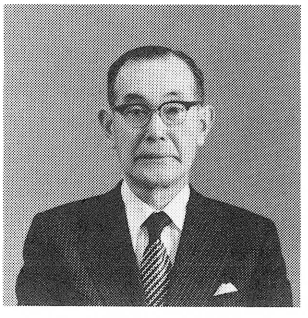
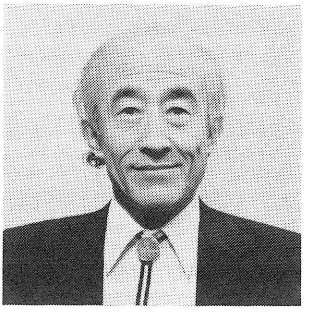
SYNOPSIS

The Concrete Committee of the Japan Society of Civil Engineers organized the Subcommittee on Granulated Blast Furnace Slag Fine Aggregate, entrusted to perform researches on concrete incorporating the fine aggregate from the Japan Iron and Steel Federation in 1980. The Recommendation for Concrete Incorporating Granulated Blast Furnace Slag Fine Aggregate was proposed as the results of extensive research works carried out in the subcommittee.

The Recommendation and the Commentary are prescribed, based on investigations in laboratories, field tests in job sites and service records in practice. This Recommendation and the Commentary present the general standards for design and construction of concrete structures incorporating water-granulated and air-granulated slag fine aggregate.



Masatane KOKUBU
Former Chairman
of
Concrete Committee



Yoshiro HIGUCHI
Chairman
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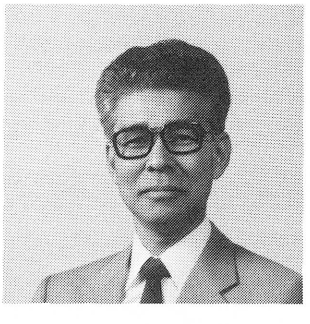

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RECOMMENDATION FOR CONCRETE INCORPORATING GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

CHAPTER 1 GENERAL PROVISIONS

SECTION 1 Scope and Principles

This Recommendation presents the general standards for design and construction of unreinforced and reinforced concrete structures using granulated blast furnace slag fine aggregate.

The items not specified in this Recommendation shall be ruled by JSCE "Standard specification for unreinforced and reinforced concrete".

SECTION 2 Definitions of Terms

Terms used in this Recommendation are defined as follows:

Granulated blast furnace slag fine aggregate:

Fine aggregate for concrete that is obtained by crushing and grading granulated slag formed when molten slag developed simultaneously with pig-iron in a blast furnace is rapidly chilled by water and/or air.

Concrete using granulated blast furnace slag fine aggregate:

Concrete made with fine aggregate consisting partially or entirely of granulated blast furnace slag fine aggregate.

CHAPTER 2 GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 3 General

(1) Granulated blast furnace slag fine aggregate shall not contain deleterious substances that may give adverse effects to the quality of concrete and embedded steel, and shall be reasonably uniform in quality.

(2) Granulated blast furnace slag fine aggregate shall conform to JIS A 5012.

SECTION 4 Grading

(1) Standard grading of granulated slag fine aggregate shall be in the range as shown in Table 1.

Table 1 Grading Requirements for Granulated Blast Furnace Slag Fine Aggregate

Class \ Nominal size of sieve mm	Weight percent passing sieve						
	10	5	2.5	1.2	0.6	0.3	0.15
5 mm slag fine aggregate	100	90 to 100	80 to 100	50 to 90	25 to 65	10 to 35	2 to 15
2.5 mm slag fine aggregate	100	95 to 100	85 to 100	60 to 95	30 to 70	10 to 45	2 to 20
1.2 mm slag fine aggregate	–	100	95 to 100	80 to 100	35 to 80	15 to 50	2 to 20
5 to 0.3 mm slag fine aggregate	100	95 to 100	65 to 100	10 to 70	0 to 40	0 to 15	0 to 10

Sieve analysis shall be in accordance with JIS A 1102.

(2) The fineness modulus of granulated blast furnace slag fine aggregate shall not vary by more than 0.20 from the value assumed in selection of the mix proportion of concrete.

SECTION 5 Limits for Deleterious Substances

The critical content of deleterious substances in granulated blast furnace slag fine aggregate that have adverse effect on the quality of concrete is as indicated in Table 2.

Other deleterious substances not prescribed in Table 2 shall be as instructed by the Engineer.

Table 2 Limits for Deleterious Substances (Weight percent)

Item	Maximum content
Total sulphur (as S)	2.0
Sulphur trioxide	0.5
Total iron (as Fe O)	3.0
Loss in washing test	7

Chemical analysis shall be in accordance with JIS A 5011.
Washing test shall be in accordance with JIS A 1103.

CHAPTER 3 QUALITY OF CONCRETE INCORPORATING GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 6 General

(1) Concrete incorporating granulated blast furnace slag fine aggregate shall secure the required strength, durability, watertightness and workability to meet the construction requirements, and show little change in quality.

(2) Concrete incorporating granulated blast furnace slag fine aggregate shall be an air-entrained concrete of an appropriate air content.

SECTION 7 Strength

Compressive strength at the age of 28 days shall as a rule provide criteria for the strength of concrete incorporating granulated blast furnace slag fine aggregate.

CHAPTER 4 HANDLING OF GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 8 Delivering and Storing Granulated Blast Furnace Slag Fine Aggregate

(1) Granulated blast furnace slag fine aggregate shall be handled to avoid segregation or degradation and prevent contamination with foreign matter. And aggregates from different sources or different gradings shall be stocked in different places.

(2) Granulated blast furnace slag fine aggregate shall not be stored over a long period of time in summer.

CHAPTER 5 PROPORTIONING OF CONCRETE MIXTURES

SECTION 9 General

The proportioning of concrete mixtures incorporating granulated blast furnace slag fine aggregate shall be established through trial mixes in principle, so as to secure required strength, durability and watertightness, and to minimize water requirement within the limits for adequate workability to meet the construction requirements.

SECTION 10 Water-Cement Ratio

(1) In case that the water-cement ratio is determined on the basis of concrete compressive strength, the water-cement ratio shall be in accordance with "Standard specification for unreinforced and reinforced concrete," **Section 95, item (1).**

(2) In case that the water-cement ratio is determined on the basis of concrete durability, the standard maximum values shall not exceed the quantities prescribed in Table 3.

Table 3 Maximum Permissible Water-Cement Ratios in Percent for Air-entraining Concrete in Case of Determining the Water-Cement Ratio on the Basis of Concrete Durability

Weather conditions / Exposure conditions of structures / Size of sections	Severe climate or frequent freezing and thawing			Mild or moderate climate, or rarely below zero		
	Thin 2)	Moderate 4)	Heavy 3)	Thin 2)	Moderate 4)	Heavy 3)
(1) Concrete in portions of structures where continuous or frequent saturation is possible 1)	55	60	60	55	65	65
(2) Ordinary exposed structures not covered by (1)	60	65	65	60	70	70

Notes 1) Saturated portions of structures near the water line, such as waterways, reservoirs, abutments, piers, retaining walls, tunnel linings, and concrete in portions of structures parted from waterline but saturated by thawed water, running water or spray, such as beams, girders, bridge decks, and other concrete work
2) Portions of structures thickness of 20 cm or less
3) Exterior portions of mass concrete
4) The other parts of structures not covered by 2) and 3)

(3) In case that the water-cement ratio is determined on the basis of concrete watertightness, the standard maximum value shall not exceed 55 percent.

SECTION 11 Consistency

Consistency of concrete incorporating granulated blast furnace slag fine aggregate shall be minimum in slump within the range ensuring appropriate workability.

SECTION 12 Air Content

(1) The standard air content of concrete incorporating granulated blast slag furnace fine aggregate shall be 3 to 6 percent of the volume of concrete, according to the maximum size of coarse aggregate and other proportioning conditions.

(2) Test shall be in accordance with JIS A 1118 or JIS A 1128.

SECTION 13 Method of Expressing Mix Proportion

(1) The specific mix proportion shall be expressed as indicated in Table 4.

Table 4 Method of Expressing Mix Proportion

Max. size of c.agg. mm	Nominal range of slump cm	Nominal range of air c. %	Water-cement ratio W/C %	Sand-agg. ratio s/a %	Weight (kg/m^3)					
					Water W	Cement C	F. agg. S	C. agg. — to ~ mm G	Admix. Mineral	Admix. AEA or Chem.

N.B.) Dosage of AEA or Chemical Admixture shall be expressed in cc or gr on the basis of undiluted liquid or undissolved powder.

(2) In the description of the specific mix proportion, the fine aggregate is to be an aggregate passing entirely the 5 mm sieve and the coarse aggregate is to be an aggregate wholly retained on the 5 mm sieve, and the weight shall be indicated on the basis of saturated surface-dry condition.

(3) In the event that the specific mix proportion is converted to the batching mix proportion, proportioning of concrete shall be carried out taking into consideration the moisture condition of aggregates, the amount of fine aggregate retained on the 5 mm sieve, the amount of coarse aggregate passing the 5 mm sieve and so forth.

CHAPTER 6 MIXING AND TRANSPORTING CONCRETE

SECTION 14 Mixing Concrete

(1) Charging materials into the mixer shall be carried out in such a manner as to charge all the ingredients uniformly at the same time as a rule.

(2) The mixing time required shall be based on the results of mixer performance tests as a rule. The standard mixing time after charging all the ingredients shall be 1 minute or more for the revolving blade type mixer, and 1 1/2 minutes or more for the tilting type mixer.

SECTION 15 Transporting Concrete

Transporting concrete shall be carried out in such a manner as to minimize segregation of ingredients and maintain uniformity.

CHAPTER 7 READY-MIXED CONCRETE

SECTION 16 General

Ready-mixed concrete shall be used in accordance with JIS A 5308 "Ready-Mixed Concrete", as a rule.

CHAPTER 8 PLACING AND CURING CONCRETE

SECTION 17 Placing and Compacting

(1) The placing of concrete shall be carried out to minimize segregation of the materials.

(2) Concrete shall be compacted fully during and immediate after depositing. To ensure proper compaction of the concrete, internal vibration shall be used as a rule.

SECTION 18 Curing

Placed concrete shall be followed by curing thoroughly so that it is not affected by low temperature, desiccation and violent temperature change.

CHAPTER 9 QUALITY CONTROL AND INSPECTION

SECTION 19 Quality Control and Inspection

Quality control and inspection of concrete containing granulated blast furnace slag fine aggregate shall be in accordance with the "Standard specification for unreinforced and reinforced concrete, **Chapter 24.**"

CHAPTER 10 PROVISIONS RELATING TO ANALYSIS AND DESIGN OF STRUCTURES

SECTION 20 General

Analysis and design of structures shall be in accordance with the "Standard specification for unreinforced and reinforced concrete, **Chapter 4**", in general.

COMMENTARY ON RECOMMENDATION FOR CONCRETE INCORPORATING GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

CHAPTER 1 GENERAL PROVISIONS

SECTION 1 Scope and Principles

This Recommendation is provided for the granulated blast furnace slag fine aggregate which conforms to JIS A 5012 "Granulated blast furnace slag fine aggregate for concrete" for use for civil engineering concrete structures in general.

Granulated blast furnace slag fine aggregate can be used for fine aggregate in concrete by itself, but in actual practice it is widely used in combination with other ordinary fine aggregates to improve the gradation, and to decrease the amounts of such harmful impurities as chlorides. There are many reports in which concrete with better workability can be obtained by this blending. Particularly, the use of granulated blast furnace slag fine aggregate will be promising and effective to improve the quality of concrete utilizing sea sand, of which the consumption is increasing rapidly as a concrete-making materials. On the other hand the annual supply capacity of granulated blast furnace slag fine aggregate in this country is only three million tonnes as of February 1982. Therefore it should be used for blending use from the view point of efficient utilization. Consequently, this Recommendation is intended to cover not only the single use of granulated blast furnace slag fine aggregate as the fine aggregate in concrete but also its combined use. In case of blended use, the quality of the combined fine aggregate should be fully taken into consideration. Particularly, when combined with sea sand, it is necessary to confirm the amount of chlorides contained in the fine aggregate to avoid adverse effects on concrete structures, with the provision of **Section 80** of JSCE "Standard specifications for unreinforced and reinforced concrete." In the case of blended use, in addition, there are many reports on the practical experience of application in which the granulated blast furnace slag fine aggregate substitutes for twenty to sixty percent of ordinary fine aggregate. The reason is chiefly that the aim of blending can be sufficiently achieved by applying this range of blending ratios.

In France and Germany, granulated blast furnace slag fine aggregate of hard and dense grain has been used for the production of structural concrete since World War 1. And at present in Saar, Luxemburg and Lorraine there are numerous examples of its application in such structures as power stations. In Japan, studies on the use of artificial sand made of conventional and soft granulated blast furnace slag go back long time, but as the production of granulated blast furnace slag fine aggregate of hard and dense grain suitable for structural concrete started just from around 1973, there is no long application experience.

Relating to the long term stability of concrete containing granulated blast furnace slag fine aggregate, no particularly abnormal signs are indicated even in the service records or survey reports of the structures existing for five to seven years in this country and several decades in France.

Therefore under the normal ambient circumstances there is no appreciable difference from that of concrete made with ordinary fine aggregate. However, when the granulated blast furnace slag fine aggregate is to be employed in such structures as important reinforced concrete structures and prestressed concrete structures, thorough investigations and experiments should be carried out in advance in the same manner as with other types of ordinary fine aggregates, as to whether satisfactory results fulfilling the construction purpose can be achieved.

It is a matter of course that cement, water, fine aggregate to be mixed, coarse aggregate and admixture should be examined for quality, even if the case of concrete production using granulated blast furnace slag fine aggregate.

SECTION 2 Definitions of Terms

Granulated blast furnace slag fine aggregate:

Granulating and rapidly chilling by water and/or air of molten slag from a blast furnace give a vitreous granular material, which is generally referred to as granulated slag. A special product that is rapidly chilled by air only is named air-granulated slag. Granulated slag, especially water-granulated slag may be divided broadly into soft product and hard one, depending upon the granulating condition, and the hard one is applied for fine aggregate for concrete.

Granulated slag chilled by water (hereinafter referred to as water-granulated slag) contains some porous and friable particles, cracked or acicular particles, or angular particles. Its rather closely graded particle size prevents it from being a suitable material for fine aggregate of concrete. On the other hand, granulated slag chilled by air (hereinafter referred to as air-granulated slag) consists mainly of spherical particles. It has a smooth surface and coarser particles. Therefore, the slag product which is on the market as a fine aggregate for concrete, is usually crushed to improve the particle shape, physical properties and grading. Air-granulated slag can be used without crushing mixed with ordinary fine aggregate making the best use of its spherical feature (e.g., a fine aggregate in conformity with 5 to 0.3 mm slag aggregate in JIS A 5012). Hereinafter, fine aggregate made of water granulated slag is called water-granulated slag fine aggregate, and fine aggregate made of air-granulated slag is called air-granulated slag fine aggregate.

From the viewpoint of utilization of slag and natural resources saving, it is necessary that the crushed sand manufactured from air-cooled blast furnace slag should be brought into use as a fine aggregate for concrete. However, for the time being, crushed air-cooled slag sand is excluded from the scope of this Recommendation, since the production processes currently used are too diverse to be able to ensure uniform product quality.

Concrete using granulated blast furnace slag fine aggregate:

In this Recommendation, the designation 'Concrete using granulated blast furnace slag fine aggregate' is given to the concrete made with fine aggregate partially or entirely of granulated blast furnace slag fine aggregate, without regard to either the presence, or the kind, or the ratio of ordinary fine aggregate to be mixed, the kind of coarse aggregate, etc.

CHAPTER 2 GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 3 General

On item (1): The quality of granulated blast furnace slag fine aggregate may not only be affected by the cooling process of molten slag and the crushing process to improve grading, but also differ in chemical composition and physical properties. However, since the commercial products of granulated blast furnace slag fine aggregate are to be delivered from well-controlled manufacturing plants, they may be considered not to have considerable variation in quality.

As granulated slags are vitreous and latent hydraulic materials, some tend to agglomerate under high atmospheric temperature during storage. Although such agglomeration of granulated blast furnace slag fine aggregate does not have a very serious effect on the quality of concrete so long as the extent of cohesion is small, this cohesion causes the hindrance of discharging of the aggregate from silos or bins where it is stored. Therefore, it is important to investigate the storage stability of the product in advance during hot weather. As the concrete using granulated blast furnace slag fine aggregate has an excellent feature in the gain of strength at later ages, an economical concrete with required quality can be obtained by taking full consideration of its characteristics.

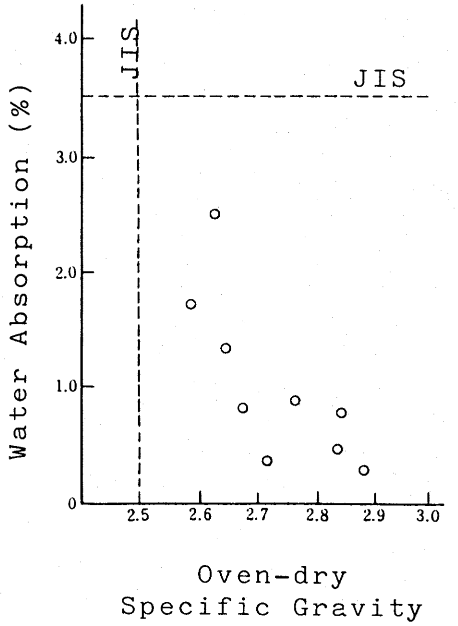
On item (2): JIS A 5012 "Granulated blast furnace slag fine aggregate" provides for four classes of granulated blast furnace slag fine aggregate, considering its blended use with ordinary fine aggregate. And this Recommendation also describes matters to be attended to, in order to apply the granulated blast furnace slag fine aggregate conforming to JIS A 5012 for single or blended use with other ordinary fine aggregates. The quality of granulated blast furnace slag fine aggregate prescribed in JIS A 5012 is as shown in Explanatory Table 1. Among the chemical components of granulated blast furnace slag fine aggregate described to be a major determinant of the chemico-mineralogical properties of the products. As to the air-cooled blast furnace coarse aggregate, the excessive calcium oxide content is likely to become a subject of discussion on the mineralogical unsoundness, due to the existence of crystallineminerals as dicalcium silicate.

Explanatory Table 1 The Quality of Granulated Blast Furnace Slag Fine Aggregate

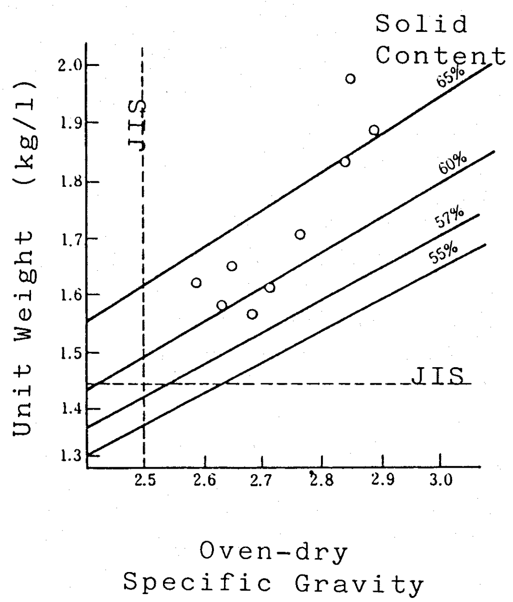
Item		Specified value
Chemical composition %	Calcium oxide	45.0 max.
	Total sulphur (as S)	2.0 max.
	Sulphur trioxide	0.5 max.
	Total iron (as FeO)	3.0 max.
Physical property	Oven-dry specific gravity	2.5 min.
	Water absorption %	3.5 max.
	Mass per unit volume kg/l	1.45 min.

Since the granulated blast furnace slag fine aggregate produced from rapidly chilled slag forms glassy phase all through the particle, it is generally believed that it may safely contain calcium oxide up to 50 percent. But as this matter is not perfectly clear yet, the value has been specified provisionally the same as that of the air-cooled blast furnace slag coarse aggregate. According to surveys of granulated blast furnace slag fine aggregate commercially produced, the content of calcium oxide ranges from 39.2 to 44.8 percent, and as to physical properties, the oven-dry specific gravity is 2.50 to 2.88, the water absorption is 0.3 to 2.5 percent, rodded unit weight is 1.57 to 1.97 kg/l, and the solid content of aggregate is 58.6 to 69.0 percent. **Explanatory Figure 1** indicates the relation between oven-dry specific gravity and water absorption, and **Explanatory Figure 2** indicates the distribution of solid content of aggregate for reference.

The determination method for saturated surface-dry condition of granulated blast furnace slag fine aggregate which is necessary for the measurement of specific gravity and water absorption is made in accordance with JIS A 1109 "Method of test for specific gravity and absorption of fine aggregate". But when granulated blast furnace slag fine aggregate contains too much dust, or fine particles to determine the saturated surface-dry condition, its sample may be prepared by washing



Explanatory Fig. 1
Relationship between Oven-dry Specific Gravity and Water Absorption



Explanatory Fig. 2
Distribution of Solid Content

in accordance with JIS A 1103 "Method of test for amount of material passing standard sieve 74 μm in aggregates."

Furthermore, in case of the determination of saturated surface-dry condition of uncrushed spherical air-granulated slag fine aggregate, its sample may be prepared by towel drying procedure to remove the water film which adheres to the surface of aggregate, as prescribed in 3.3 of JIS A 1110 "Method of test for specific gravity and absorption of coarse aggregate."

SECTION 4 Grading

On item (1): Grading requirements described in Table 1 are to specify the standard ranges of grading, in which 5 mm slag fine aggregate is that in case of single use, the other classes are generally those in case of blended use mainly with ordinary fine aggregate. These grading requirements are quite the same as described in JIS A 5012. But even in the use of 5 mm slag fine aggregate, it may be often mixed with ordinary fine aggregate depending on the purport of use. Furthermore 2.5 mm slag fine aggregate and 1.2 mm slag fine aggregate which also conform to the grading requirement of 5 mm slag fine aggregate can be used singly for concrete.

In case of 5 mm slag fine aggregate, the weight percentage passing nominal sieve of 0.15 mm is 2 to 15 percent, that is, greater margin than in the range described in **Section 77** "Grading requirement" of the "Standard specifications of unreinforced and reinforced concrete." This reflects the fact that the smaller the aggregate particle size, the greater is its specific gravity, and consequently the weight percentage value should be greater, if the volume percentage of particle size distribution is equal to that in the normal specification. Another fact to be considered is that the greater the quantity of fine particles, the better becomes the workability and the less is the bleeding of concrete since the particle shape is somewhat angular.

When granulated blast furnace slag fine aggregate is mixed with other ordinary fine aggregate, and the bulk of materials passing a 0.15 mm sieve is made up of granulated blast furnace slag fine aggregate, the resultant might well be limited to 15 percent, and for other size ranges the same values as are described in **Section 77** of the "Standard specifications of unreinforced and reinforced concrete shall apply.

In the combined use of granulated blast furnace slag fine aggregate, the blending ratio should be chosen by test to make an economical concrete of the required quality taking into consideration the facts mentioned above.

An investigation on the actual condition of commercial products shows that the fineness modulus is 2.8 to 3.2 for 5 mm slag fine aggregate, 2.5 to 2.7 for 2.5 mm slag fine aggregate, 2.0 to 2.4 for 1.2 mm slag fine aggregate, and 3.0 or more for 5 to 0.3 mm slag fine aggregate.

On item (2): In the manufacturing process of granulated blast furnace slag fine aggregate, close attention is paid to minimize the variation of gradation and actual variation of fineness moduli of commercial products are in the order of ±0.15 to 0.20. As in the case of combined use with ordinary fine aggregate, it is quite proper to minimize the variation of fineness modulus of ordinary fine aggregate. And if the fineness modulus of combined fine aggregate varies by more than 0.20 from the value assumed in selecting proportions for the concrete, suitable adjustments shall be made in concrete proportions in the same manner as that being practiced in general.

SECTION 5 Limits for Deleterious Substances

As to critical content of deleterious substances in granulated blast furnace slag fine aggregate that have adverse effect on the quality of concrete, this Recommendation provides both the items described in JIS A 5012 "Granulated blast furnace slag fine aggregate for concrete" as components proper contained in slag itself, and fine material lost in washing test, as is specified in **Table 2**. Other deleterious substances that may be present in ordinary fine aggregate include generally organic impurities, coal or lignite that float on the liquid of specific gravity 1.95, clay lumps, etc.. In the production process of granulated blast furnace slag fine aggregate, the contamination by these deleterious substances is unlikely to occur in general. There are some lighter particles of slag aggregate floating on the liquid that has specific gravity of 1.95. Thery are soft particles that are yielded in a small amount at the time of granulating and chilling. These particles are different from coal or lignite which may detract from the appearance by producing surface stains and scalings, so no provisions are prescribed on this matter. In the ordinary production of granulated blast furnace slag fine aggregate conforming to JIS, the use of sea water or foul water as granulating and chilling water it is hardly expected, so it is unlikely that dust, dirt, organic impurities, salts, etc. will enter the product.

On total sulphur and sulphur trioxide: Since sulphur contained in granulated blast furnace slag fine aggregate is dispersed in the glass phase of the rapidly chilled slag, it is hardly eluted or oxidized in contrast with the one in air-cooled crystalline slag. Therefore, it scarcely seems to corrode the embedded steel or react with tricalcium aluminate (C_3A) in cement, and this point is much different from the case of air-cooled blast furnace coarse aggregate. But to be on the safe side, this Recommendation adopts the same value as specified in the stipulation of air-cooled blast furnace coarse aggregate.

An investigation on the actual condition of commercial products shows that the total sulphur content is 1.4 percent maximum and 0.86 percent on the average and that sulphur trioxide content is 0.28 percent maximum and approximately 0.06 percent on the average. These figures amply satisfy the limits specified in Table 2.

On total iron: Ferrous metal contained in granulated blast furnace slag fine aggregate may produce stains on the surface of concrete due to oxidation or rusting. It may safely be said that a total iron content of 3 percent or less will virtually eliminate the fear of oxidation.

The above investigation shows the maximum total iron content is 1.2 percent and the average is approximately 0.37 percent.

On loss in washing test: Granulated blast furnace slag fine aggregate is apt to contain a considerable amount of fine particles, due to processing the granulated slag by crushing. The amount of fine material passing the sieve of 0.074 mm is roughly half as much as the percentage passing the sieve of 0.15 mm, owing to the mechanical breaking characteristics of crushers. Therefore, if the upper limit of weight percentage passing the sieve of 0.15 mm is taken to be 15 percent, the amount of material lost in the washing test will run up to approximately 7 percent.

The above investigation on the commercial products shows that the value ranges 1 to 7 percent in 5 mm slag fine aggregate, 2 to 7 percent in 2.5 mm slag fine aggregate, 3 to 7 percent in 1.2 mm slag fine aggregate and 1 to 3 percent in 5 to 0.3 mm slag fine aggregate, and is situated for the most part at 4 to 5 percent, with a tendency to increase the percentage with the decrease of fineness modulus of the aggregate.

The fine material that does not belong in clay or silt which exists frequently in ordinary fine aggregate, may be considered to give little adverse effect on concrete, if prepared to the properly proportioned mix. It is also reflected from the results of some experiments that the slag fines reduce the bleeding water of concrete and give no adverse effect on the workability of concrete, but rather bring better results to the performance of concrete, serving as a kind of cementing material at later ages.

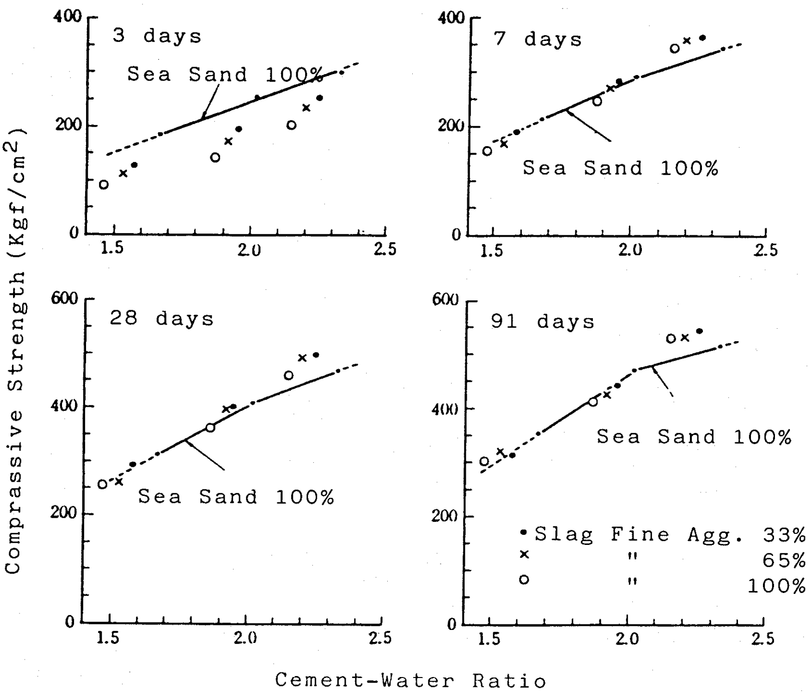
Considering the utilization of the granulated blast furnace slag fine aggregate, it is desirable to use as much slag fines as possible. However, an excess of fines may yield excessive plastic and sticky concrete. In addition, it may cause difficulty in control of the surface moisture in the aggregate, and impair the stability during storage under high atmospheric temperature. Considering this, the limit of loss percentage by washing test is decided to be 7 percent to ensure the uniform and stable quality of concrete.

CHAPTER 3 QUALITY OF CONCRETE INCORPORATING GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 6 General

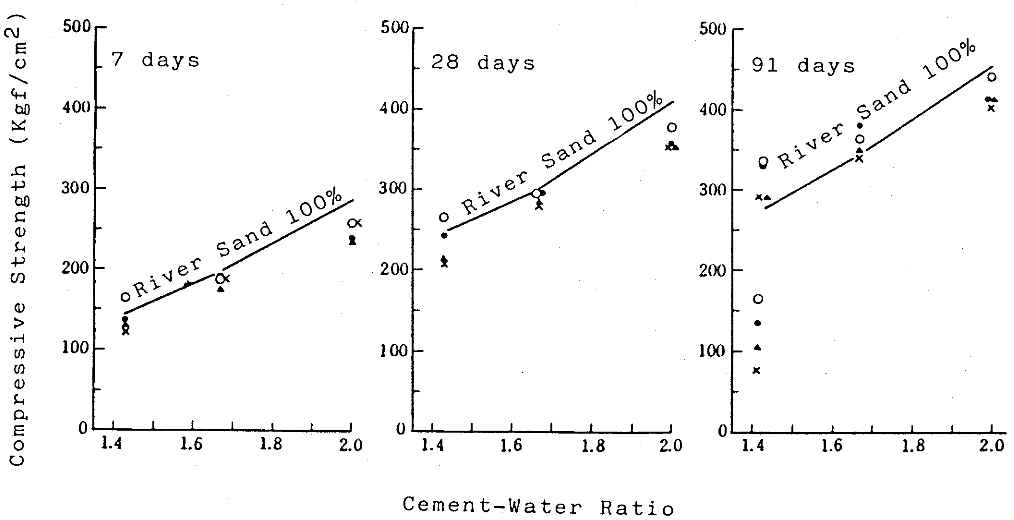
Such qualities as strength, durability, watertightness, etc., of concrete containing granulated blast furnace slag fine aggregate must satisfy the criterion on the analysis and design of structures. In addition, the concrete shall be of suitable workability that meets the construction purpose, so as to achieve satisfactory consideration and obtain uniform concrete. Although these qualities are considerably different depending on materials to be employed, concrete mixes, and methods of concreting, it is easy to obtain about the same quality of concrete as that of concrete made with ordinary fine aggregate, so long as the design and construction is carried out in accordance with the Recommendation.

On strength: Compared with the concrete made using ordinary fine aggregate with the same water-cement ratio, concrete containing granulated blast furnace slag fine aggregate is liable to become lower in compressive strength at an earlier age. This tendency increases with a higher blending ratio of granulated blast furnace slag fine aggregate. But the lowered strength will recover gradually with the passage of curing age. For instance, the compressive strength of concrete containing granulated blast furnace slag fine aggregate increases no less than that of concrete with 100 percent sea sand at the age of 7 days, as indicated in **Explanatory Figure 3**. And compared with quality river sand, the granulated blaster furnace slag fine aggregate can often make rather stronger concrete after 91 days, as indicated **Explanatory Figure 4**. The compressive strength of concrete using air-granulated slag fine aggregate after 7 days is nearly equal to that of concrete made with the quality river sand. Especially, as the uncrushed air-granulated slag fine aggregate can reduce the water requirement of concrete, the compressive strength after 7 days is 5 to 15 percent higher than that of concrete made with sea sand alone, as indicated in **Explanatory Figure 5**.



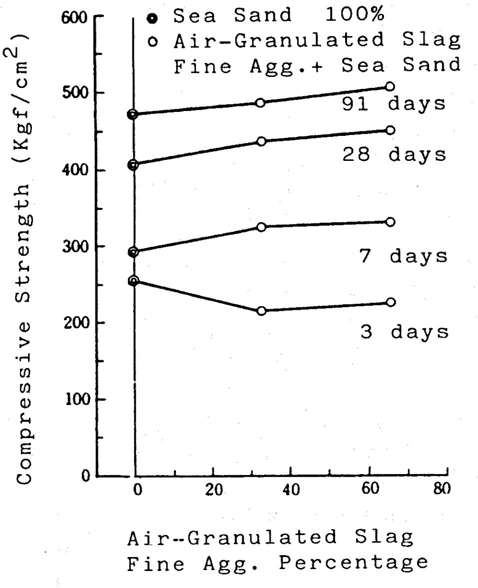
Explanatory Fig. 3

Example of Relationship between Compressive Strength and Cement-Water Ratio of Concrete (Water-Granulated Slag Fine Aggregate, Slump = 10cm, Air Content = 4.0%, Max. Size = 20mm, Normal Portland Cement, 20°C Water Curing)

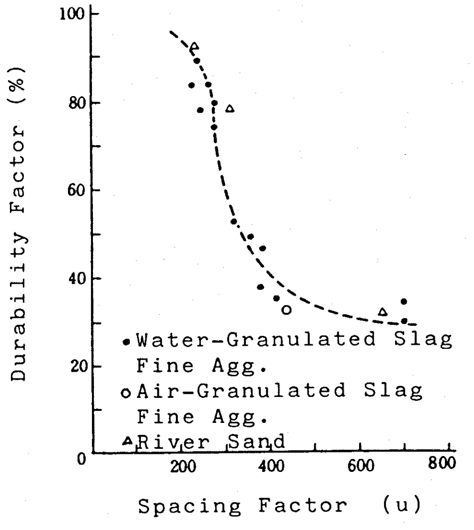


Explanatory Fig. 4

Example of Relationship between Compressive Strength and Cement-Water Ratio of Concrete (Water-Granulated Slag Fine Aggregate, Slump = 8cm, Air-Content = 4.5%, Max. Size = 20mm, Normal Portland Cement, 20°C Water Curing)



Explanatory Fig. 5
Example of Relationship between Percentage of Air-Granulated Slag Fine Aggregate and Compressive Strength of Concrete (Max. Size = 20mm, Cement Content = 340kg/m^3, Slump = 10cm, Air Content = 4.0%, Normal Portland Cement, 20°C Water Curing)



Explanatory Fig. 6
Relationship between Air-Void-Spacing Factor and Durability Factor of Concrete

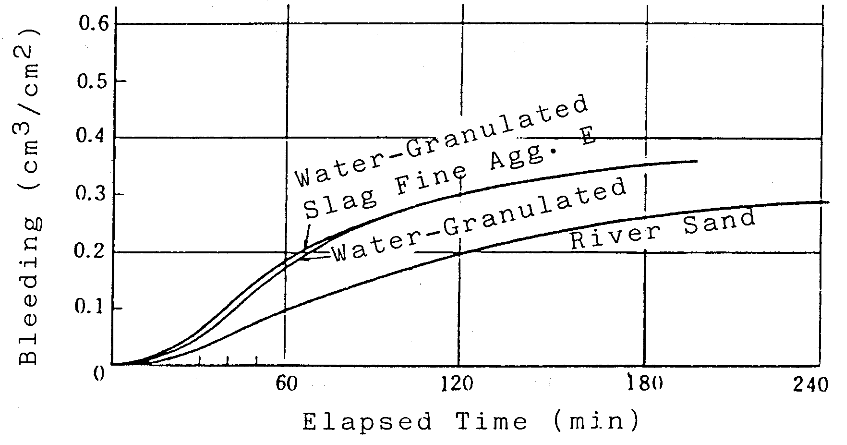
Tensile strength, flexural strength, Young's modulus, bond strength with reinforcing steel of concrete with granulated blast furnace slag fine aggregate are considered to be practically equivalent to those of ordinary fine aggregate of the average level as far as the same compressive strength is obtained, although they may differ a little depending on the conditions of producing granulated blast furnace slag fine aggregate.

On durability: Resistance to freezing and thawing of the concrete containing granulated blast furnace slag fine aggregate conforming to JIS A 5012, can be considered to be equivalent to those for ordinary fine aggregate of the average level, so far as air-entrained concrete with a sufficient amount of air volume that ensures the air-void spacing factor of less than about 250 μm is obtained, as indicated in **Explanatory Figure 6**. In addition, since larger amounts of entrapped air are contained in concrete made only with granulated blast furnace slag fine aggregate than that with ordinary fine aggregate, it follows that the total air content must be chosen by carefully considering this effect.

As the durability of concrete is generally governed by air content and water-cement ratio so long as the quality of aggregate is equal, entrained air should be used in all the concrete containing granulated blast furnace slag fine aggregate, and the water-cement ratio should be selected not to exceed the limits specified in **Chapter 5, Section 10**.

On watertightness: As to the watertightness of concrete containing granulated blast furnace slag fine aggregate, very little information and data are available but every test result shows that it is generally equal to that for ordinary aggregate. Therefore, for watertightness it is recommendable, as is in the same manner, as in ordinary concrete, to use appropriate admixtures, and make an air entrained concrete in which the water-cement ratio does not exceed the limits specified in **Chapter 5, Section 10**.

On workability: Since granulated blast furnace slag fine aggregate is manufactured through the process of crushing, it contains more angular particles than river sand. And because of its vitreous structure, water retention is less than that of river sand whilst surface texture of grains is smooth. For this reason, water requirement of the concrete made with such a granulated blast furnace slag fine aggregate is generally higher, and more bleeding water is produced than that for river sand, even though using identical concretes of the same slump as shown in the **Explanatory Figure 7**. On the other hand, in case of the blended use of uncrushed air-granulated slag fine aggregate and ordinary fine aggregate, increased water bleeding may occur depending on the selection of the blending ratio of aggregates or the mix proportioning of concrete, though some



Explanatory Fig. 7
Example of Test Results on Bleeding of Concrete (W/C = 60%, Slump = 8cm, Water-Reducing Admixture Used)

reports state that air-granulated slag fine aggregate has a tendency to improve the workability of concrete by reducing the water content. Consequently, the concrete containing granulated blast furnace slag fine aggregate must be air entrained, to make better workability of concrete.

SECTION 7 Strength

In the same manner as in conventional concrete, flexural strength, tensile strength, shear strength, bond strength with reinforcing steel, etc. of concrete with granulated blast furnace slag fine aggregate are not always proportional to compressive strength, but these strengths can be deduced roughly from compressive strength as long as concrete work applied is secure in adequate state.

Under properly cured condition, compressive strength of concrete containing granulated blast furnace slag fine aggregate increases significantly even after 28 days, and the rate of gain of strength often becomes larger than that in the case of conventional concrete made with ordinary fine aggregate. But this extent of gain in compressive strength may differ depending on the blending ratio of fine aggregate combined. As to the criterion of concrete strength in ordinary structures, therefore, the 28 days compressive strength of concrete test specimens cured in standard conditions is herein taken to be standard, as practiced in concrete work in general.

CHAPTER 4 HANDLING OF GRANULATED BLAST FURNACE SLAG FINE AGGREGATE

SECTION 8 Delivering and Storing Granulated Blast Furnace Slag Fine Aggregate

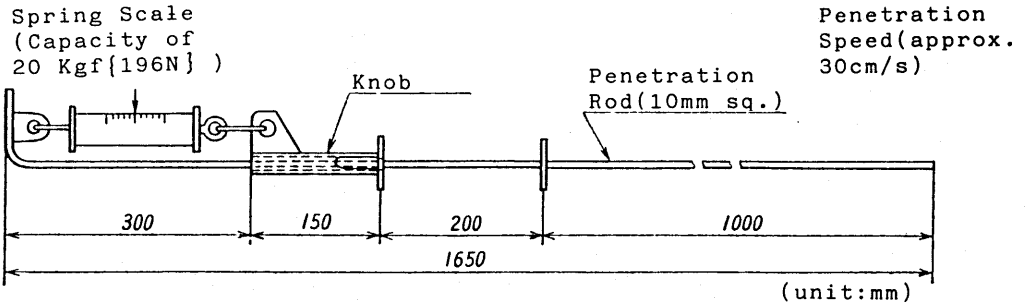
On item (1): Damp fine aggregates have less tendency to segregate. But with uncrushed air-granulated slag fine aggregate of spherical form precaution should be exercised in handling, because of a greater tendency for segregation of small and large particles. In particular, since the uncrushed air-granulated slag fine aggregate of spherical form is used by blending other fine aggregates, it is advisable to store it by making a uniformly pre-blended aggregate in advance. Care must be taken as to the storage of dry, fine aggregate, not to allow it to free from an elevated spot.

Damp aggregate shall be deposited and drained until the moisture content becomes reasonably uniform. On the other hand, there is danger of large workability variation during concrete transporting and handling due to elevated temperature, so it is necessary to prevent an aggregate temperature rise through such measures as shielding it from the sun or sprinkling water over it in the storage. Such precautions as these in hot weather may contribute to prevent cohesion of the granulated blast furnace slag fine aggregate.

On item (2): Particles of granulated blast furnace slag fine aggregate are apt to show agglomerating or cohering phenomenon when the average air temperature is above 20°C. When cohesion makes progress, it impairs the manufacture of concrete hindering the discharge of the aggregate from the storage place, or batching bin compartments. It is, therefore, recommendable that granulated blast furnace slag fine aggregate be purchased on purpose so that it can be used as soon as possible after delivery during the period from late in April through October.

When purchasing the product between late April and October, check must be made of the certificate completed in accordance with "The test method for storage stability of slag fine aggregate" provided in JIS A 5012. The material whose storage stability is judged 'A' is evaluated as less cohesive, whilst the material whose storage stability is judged 'B' is evaluated as fairly cohesive. Among the products of judgement 'A', there exist some materials that are subjected to processing to inhibit cohesion. Such materials as the above can be stored for several weeks.

As for the condition of agglomeration of the material delivered, it is desirable to be controlled by conducting test. And, as to the actual checking procedures, it is convenient to apply not only the visual inspection but also the sounding test using penetration resistance measuring instrument



Penetrating Resistance Coefficient =

$$\frac{\text{Spring Scale Load at 100cm Penetration(kgf)}}{\text{Penetration 100 (cm)}}$$

or $$\frac{\text{Spring Scale Maximum Load 20 kgf}}{\text{Penetration Depth at Spring Scale Max.Load (cm)}}$$

Explanatory Fig. 8
Penetration Resistance Measurement Instrument

as illustrated in **Explanatory Figure 8.**

Penetration resistance coefficient of un-cohered granulated blast furnace slag fine aggregate immediately after production or ordinary fine aggregate of natural source is about 0.1 to 0.2. It is considered that the penetration resistance coefficient of the aggregate in which cohered particles can not be found, is 0.45 or less, and such a material as this can safely be used without hindering the discharge of the aggregate from the storage place or without changing such qualities as specific gravity, water absorption, etc.. In addition, there is an example of a test, in which the cohered material of penetration resistance coefficient about 10 is reworked and beneficiated by crushing and used in concrete. In this test, concretes made with this fine aggregate indicates no significant change in workability, strength, and even durability. Therefore, it is concluded that such a granulated blast furnace slag fine aggregate as can be safely extracted from storage bins, even though cohered, is good enough to be used for concrete without adverse effect on the quality of concrete. However, it is necessary that granulated blast furnace slag fine aggregate should not cohere in storage, or in the batching bins, so as to ensure smooth concrete production. For this purpose, it is important to make efforts to use the product as soon as possible or to prevent the cohesion by tearing up the stockpiles by bulldozers or other ripping machines, when the penetration resistance coefficient begins to increase at the daily controlling test. To avoid temperature increase of the product during storage, such measures as water sprinkling on the surface of stockpiles, water injection to the interior through an inserted pipe and shielding from direct sun light are effective, yet alkaline water as recovered from washing the concrete manufacturing plant should not be used as cooling water for the product. In case that granulated blast furnace slag fine aggregate is used in combination with ordinary fine aggregate, it can be stored easily for an extended period of time by thoroughly premixing ordinary fine aggregate 25 percent or more.

As to the type of storage, stockpiles are comparatively easy to reclaim even when the product is cohesive, but barrel-shaped silos of corrugated metal sheets will show marked difficulties in extracting the cohered product. Therefore, in case of such types of storage, it is necessary to alter the structure of the vessel, or to pay much more attention to the control level of cohesion.

CHAPTER 5 PROPORTIONING OF CONCRETE MIXTURES

SECTION 9 General

This general provision specifies basic principles for determining the mix proportions of concrete, which shall be selected so as to provide suitable workability for concrete work, required strength and durability, and, as necessary, sufficient watertightness.

In proportioning the mix of concrete containing granulated blast furnace slag fine aggregate, it is also equally important to make efforts to minimize water requirement within the limits to obtain the required workability, while securing the water-cement ratio at required value, as in the case of conventional concrete made with ordinary fine aggregate.

Since the quality of granulated blast furnace slag fine aggregate varies to some extent by the manufacturing plant, it is especially important that the proportioning of concrete mixes shall be established through trial mixes with the use of materials to be employed in the proposed job under expected service conditions.

SECTION 10 Water-Cement Ratio

On item (1): Also in concrete containing granulated blast furnace slag fine aggregate, as in the case of conventional concrete made with ordinary fine aggregate, a linear relationship is present between compressive strength and cement-water ratio. Therefore, when water-cement ratio must be determined on the basis of required compressive strength, this relationship is to be utilized in calculation. The relationship between cement-water ratio and compressive strength varies with not only the types of cement, but also source or class of granulated blast furnace slag fine aggregate, or blending ratio with other fine aggregate. Therefore, the water-cement ratio shall be determined based on the relationship between cement-water ratio and compressive strength, which results from a series of test batches.

Compressive strength of concrete containing granulated blast furnace slag fine aggregate for the most part of fine aggregate increases considerably after 28 days, under proper curing condition. This is a bonus effect of latent hydraulic property of granulated blast furnace slag fine aggregate. Therefore, when adequate curing conditions and period before loading can be expected, it is considered economical to determine the water-cement ratio on the basis of the greatest permissible age as a design criterion.

On item (2): It is well recognized that concrete containing granulated blast furnace slag fine aggregate has the same resistance to freezing and thawing as conventional concrete made with ordinary fine aggregate with the same water-cement ratio, as long as the air-void spacing factor, L, is equal. Therefore, in case that the water-cement ratio is determined on the basis of durability, the maximum permissible water-cement ratios are to be the same as described in the **Section 95, item (2)** of the "Standard specifications for unreinforced and reinforced concrete."

In case of special conditions, such as those for concrete exposed to soil or ground water containing sulphate concentrations (SO_4) of more than 0.2 percent, or those for concrete protected from the weather or concrete below ground, water-cement ratios shall be determined in accordance with that described in the **Section 95, item (2)** of the "Standard specifications of unreinforced and reinforced concrete."

On item (3): When the concrete containing granulated blast furnace slag fine aggregate of appropriate consistency, is deposited with minimum segregations, then consolidated fully and cured satisfactorily its watertightness is the same as that of concrete made with ordinary fine aggregate. Thereby, the water-cement ratio is determined on the basis of watertightness in the same manner as that being practiced in ordinary concrete mixes.

SECTION 11 Consistency

Since the workability of concrete containing granulated blast furnace slag fine aggregate can be considered to be the same as that of concrete using ordinary fine aggregate of the same slump, provided that the mix proportion is properly selected, so the slump of concrete containing granulated blast furnace slag fine aggregate may just as well be selected according to that being practiced in conventional concrete made with ordinary fine aggregate.

Because of angular shape, water-granulated blast furnace slag fine aggregate tends to require 4 to 8 percent more water content than high-quality river sand for obtaining the required slump. However, when the blending ratio of granulated blast furnace slag fine aggregate is less than 50 percent, no appreciable difference can be noticed in the water requirement of concrete.

On the other hand, in case of blended use of uncrushed spherical air-granulated slag fine aggregate and ordinary fine aggregate, the water requirement can be reduced. For instance, at a blending ratio of 50 percent with sea sand, water requirement can be 6 to 10 percent lower than with single sea sand.

In case that the ordinary fine aggregate is poor in gradation as seen usually in practice, not only air-granulated alsg fine aggregate but also water-granulated slag fine aggregate is often employed to improve the gradation by blending. And if the blending ratio is properly selected, the water requirement of concrete is reduced even in the case of water-granulated slag fine aggregate.

Sand-aggregates ratio is not so much different from that of concrete made with ordinary fine aggregate. However, as this ratio varies with quality of granulated blast furnace slag fine aggregate, blending ratio, proportioning requirements of concrete, kind of admixtures and so forth, it should be determined through trial batches in advance with the use of materials to be employed in the proposed job, so as to minimize water requirement within the limits to obtain the required workability.

SECTION 12 Air Content

On item (1): In the present state of circumstances, granulated blast slag fine aggregate is mostly used combined with ordinary fine aggregate. As the concrete made with blended sand of which the blending ratio is up to 50 percent, shows no difference in freezing and thawing resistance as compared with that with ordinary fine aggregate, the required amount of air is the same value, 3 to 6 percent, as the ordinary concrete.

However, since granulated blast furnace slag fine aggregate is inclined to induce more air entrapment during concrete mixing, it is necessary, in some cases of single use of granulated blast furnace slag fine aggregate, that the air content be higher to some extent than the above value, so as to eliminate the air-void spacing factor and enhance the ability of concrete to resist the effect of freezing and thawing.

When the granulated blast furnace slag fine aggregate is employed for the greater or entire part of fine aggregate in concrete, the dosage of air entraining admixture to provide a prescribed air content should be carefully considered, because this dosage is likely to be smaller than for ordinary fine aggregate.

On item (2): In testing the air content, either the volumetric method (JIS A 1118) or the pressure method (JIS A 1128) can be adopted.

SECTION 13 Method of Expressing Mix Proportion

As the proportioning of concrete incorporating granulated blast furnace slag fine aggregate is not different in principle from that of ordinary concrete, the method of expressing mix proportion shall be in accordance with the **Section 103** of the "Standard specification for unreinforced and reinforced concrete."

However, in addition, when the granulated blast slag fine aggregate is used as a blended fine aggregate, each kind or source of fine aggregate and blending ratio shall be described in the table.

CHAPTER 6 MIXING AND TRANSPORTING CONCRETE

SECTION 14 Mixing Concrete

Mixing of the concrete using granulated blast furnace slag fine aggregate is made in the same manner as conventional concrete.

SECTION 15 Transporting Concrete

The transport of the concrete containing granulated blast furnace slag fine aggregate may be made in the same manner as conventional concrete.

CHAPTER 7 READY-MIXED CONCRETE

SECTION 16 General

As for ready-mixed concrete containing granulated blast furnace slag fine aggregate, its quality, proportioning, production, delivering, testing, inspection, etc. are not different fundamentally from those of concrete containing ordinary fine aggregate. It is, therefore, recommended that the ready-mixed concrete containing granulated blast furnace slag fine aggregate be dealt with in accordance with JIS A 5308 "Ready-mixed concrete." However, there are some points requiring special consideration such as handling of materials, selection of proportioning, etc.. As to such matters, care should be paid, reflecting the purport described in each section of this Recommendation.

CHAPTER 8 PLACING AND CURING CONCRETE

SECTION 17 Placing and Compacting

Placing and compacting of concrete containing granulated blast furnace slag fine aggregate may be carried out in the same manner as those of conventional concrete. However, care should be taken to note that bleeding is somewhat larger and quicker, depending on the blending ratio of granulated blast furnace slag fine aggregate, or mix proportion of the concrete. And attention should be paid in execution since some reports indicate the tendency to have a quicker setting time.

SECTION 18 Curing

Curing of the concrete containing granulated blast furnace slag fine aggregate may be carried out in the same manner as that of conventional concrete. However, since the granulated blast furnace slag fine aggregate is vitreous, and has a thermal diffusivity slightly less than that of ordinary fine aggregate, special precaution should be taken as to estimating the thermal diffusivity of concrete containing granulated blast furnace slag fine aggregate when the temperature variation caused by heat of hydration needs to be calculated for such massive structures as dams.

CHAPTER 9 QUALITY CONTROL AND INSPECTION

SECTION 19 Quality Control and Inspection

Quality control and inspection of concrete using granulated blast furnace slag fine aggregate shall be in accordance with the "Quality control and inspection" specified in "Standard specification for unreinforced and reinforced concrete." In addition, the control method for cohesion of granulated blast furnace slag fine aggregate during storage should be established according to the circumstances of work referring to the commentary of **Section 8 (2).**

CHAPTER 10 PROVISIONS RELATING TO ANALYSIS AND DESIGN OF STRUCTURES

SECTION 20 General

Stipulations in the "Standard specification for unreinforced and reinforced concrete, **Chapter 4**" shall be applicable to the concrete containing granulated blast furnace slag fine aggregate.

However, because of little actual experience of application of granulated blast furnace slag fine aggregate, it is necessary to fully examine, by carrying out close and thorough investigations and experiments, prior to employing it in important structures.

Interrelationship between various types of strength or the design constants as Young's modulus, Poisson's ratio, etc., that are applied to concrete containing granulated blast furnace slag fine aggregate, are explained by the results of experiments as follows:

Relation between compressive strength and Young's modulus of the concrete containing granulated blast furnace slag fine aggregate is similar to that with river sand. And it should also have a Poisson's ratio of 0.16 to 0.22, the same as that of river sand.

Relations of compressive strength with other types of strength of the concrete containing granulated blast furnace slag fine aggregate have the same tendencies as those of ordinary fine aggregate.

Drying shrinkage of concrete containing granulated blast furnaçe slag fine aggregate tends to be equal to or less than that with river sand.

Creep coefficient tends to be equal to or a little larger than that with ordinary fine aggregate.

Thermal expansion coefficient is about $1.0 \times 10^{-5}/^{\circ}C$ which is not much different from that with ordinary fine aggregate.

Furthermore, since carbonation rate and bond strength of reinforcement are the same as those with ordinary fine aggregate, such items as joints, anchorages and covers of reinforcement may be dealt with those as with ordinary fine aggregate.

APPENDICES

Abstract of Japanese Industrial Standard
1. Granulated Blast Furnace Slag Fine Aggregate for Concrete
(JIS A 5012 – 1981)

1. Scope
2. Meaning of Terms
3. Classes

The slag fine aggregate is classified as specified in **Table 1.**

Table 1

Class	Particle Size, mm
5 mm slag fine aggregate	5 max.
2.5 mm slag fine aggregate	2.5 max.
1.2 mm slag fine aggregate	1.2 max.
5 to 0.3 mm slag fine aggregate	5 to 0.3

4. **Quality**

4.1 The slag fine aggregate shall not include the deleterious substances which may affect adversely the quality of concrete.

4.2 The slag fine aggregate shall be tested on chemical composition and physical properties in accordance with **5.1** through **5.3**, and the results shall conform to the requirements of **Table 2.**

Table 2

Item		Specified value
Chemical composition %	Calcium oxide	45.0 max.
	Total sulphur (as S)	2.0 max.
	Sulphur trioxide	0.5 max.
	Total iron (as FeO)	3.0 max.
Physical property	Oven-dry specific gravity	2.5 min.
	Water absorption, %	3.5 max.
	Mass per unit volume, kg/l	1.45 min.

4.3 The slag fine aggregate shall be tested on particle size in accordance with 5.4, and the results shall comply with the requirements of Table 3.

Table 3

Nominal size of sieve, mm / Class	Weight percent passing sieve						
	10	5	2.5	1.2	0.6	0.3	0.15
5 mm slag fine aggregate	100	90 to 100	80 to 100	50 to 90	25 to 65	10 to 35	2 to 15
2.5 mm slag fine aggregate	100	95 to 100	85 to 100	60 to 95	30 to 70	10 to 45	2 to 20
1.2 mm slag fine aggregate	–	100	95 to 100	80 to 100	35 to 80	15 to 50	2 to 20
5 to 0.3 mm slag fine aggregate	100	95 to 100	65 to 100	10 to 70	0 to 40	0 to 15	0 to 10

4.4 The fineness modulus of the slag fine aggregate shall not vary by ±0.20 or more from that determined by the test for the sample submitted by the producer at the time of contract.

4.5 The stability of the slag fine aggregate during storage under high atmospheric temperature shall be confirmed by agreement between the parties concerned.

Reference 1. For confirming the stability during storage, the test shall be made in accordance with the Test Method for Storage Stability of Slag Fine Aggregate described in Reference 2, and the material is evaluated as stable, when the result of judgment falls under A.

5. Tests

5.1 Chemical Analysis

5.2 Test for Oven-Dry Specific Gravity and Water Absorption

5.3 Tests for Mass per Unit Volume

5.4 Tests for Particle Size

6. Inspection

7. Marking

Reference 2. Test Method for Storage Stability of Slag Fine Aggregate

1. Scope

2. Testing Apparatus

2.1 Autoclave

2.2 Testing Vessel

2.3 Mixer

2.4 Dryer for Measuring of Moisture

2.5 Rammer

2.6 Spoon

2.7 Spatula

2.8 Cover of Testing Vessel

2.9 Weighing Machine

2.10 Flow Table

3. Sample

3.1 Sampling

3.2 Preparation of Sample The sample is prepared as follows:

(1) Immediately reduce the sample taken by a suitable method to make two samples weighing about 650 g each. Store one of the sample enclosed airtight at 15°C or under as a spare sample.

(2) Add purified water specified in JIS K 0211 to the sample so as its water content becomes 10 ± 3%, stir it with the mixer until the water content is homogeneous, and hastily furnish it to making the test specimen described in 4.1.

4. Testing Procedure

4.1 Making Test Specimens Test specimens shall be made as follows:

(1) Hastily make three test specimens from the sample prepared as described in 3.2 in accordance with the following procedure.

(2) Weigh out 150 g of the sample, and put it in the testing vessel with the spoon.

(3) Place the testing vessel containing the sample on the flow table, compact the sample by giving 75 dropping motions at a rate of 1 stroke per second, then uniformly tamp the surface of the sample by freely dropping the rammer on it 15 times to make it flat.

4.2 Autoclave Processing Perform the autoclave processing as follows:

(1) Set the pressure regulator beforehand so as it maintains 15 ± 1 kgf/cm^2 {1.47 ± 0.098 MPa}.

(2) Pour in the tank of autoclave water enough to keep the autoclave saturated with steam throughout the whole testing period of the autoclave processing.

(3) Put the three test specimens made at the same time, together with the testing vessel, on the table in the autoclave, and put a cover on each testing vessel.

(4) Close the autoclave airtight, and start heating with the exhaust valve open. Close the exhaust valve at about 50°C, and open it again at about 90°C for a few second to purge air.

(5) After closing the exhaust valve at about 50°C, make heating so as the gauge pressure rises to 15 kgf/cm^2 {1.47 MPa} in about 60 min.

(6) Keep the gauge pressure at 15 ± 1 kgf/cm^2 {1.47 ± 0.098 MPa} for 2 h.

(7) Stop heating, and make cooling so as to the gauge pressure falls to 0.5 kgf/cm^2 {0.049 MPa} or under after 1.5 h. Further, open the exhaust valve little by little so as the temperature falls to 100°C or under in about 2 h of stopping heating.

(8) Open the autoclave, and take out the testing vessels containing test specimens.

(9) Dip the testing vessels containing test specimens in the water held in a tank to a depth equal to about 2/3 the height of testing vessel, and cool them until they can be felt with fingers.

4.3 Judgment Test The judgment test shall be made as follows:

(1) Turn over a testing vessel containing test specimen upside down on the flow table. If the test specimen will not fall out, loosen the interface between the inside wall of testing vessel and the test specimen by tapping the bottom of testing or with the spatula to make it fall out on the flow table.

(2) if the test specimen is compacting in lumps of a size of about 10 mm or over, separate other smaller particles avoiding their contact with the compacting lumps, and give the lumps dropping motions at a rate of 1 drop per second.
Record the number of dropping motions required until all the lumps break to a size of about 10 mm or less. The number of dropping motions is limited to 40.

5. Results and Judgment

5.1 Divide the test result on each test specimen by the aid of Reference Table 1.

Reference Table 1

Number of dropping motions required until lumps break to about 10mm or under	Division
0 to 10	a
11 to 40	b
If lumps do not break to about 10mm or under by 40 dropping motions	c

5.2 Make judgment as indicated in **Reference Table 2** from the results obtained from three test specimens tested at a time.

Reference Table 2

Results of division of three test specimens			Judgment
a	a	a	A
a	a	b	A
a	b	b	B(2)
b	b	b	B
If one or more c are included			B

Note: (2) Retest may be made for the spare sample.

2. Main Points of Commentary of Japanese Industrial Standard Granulated Blast Furnace Slag Fine Aggregate for Concrete

1. Scope

This standard shall apply to fine aggregate for concrete produced by subjecting molten slag, which is developed simultaneously with pig-iron in a blast furnace, to rapid chilling by water, air, etc., and to grading by size.

It should be noted that fine aggregate produced by crushing air-cooled slag is excluded from the scope of this Standard, since the production processes currently used are too diverse to be able to assure uniform product quality.

2. Meaning of Terms

There are two types of slag fine aggregate: water-chilled and air-chilled. Slag rapidly chilled by water generally contains some porous and friable particles and cracked or acicular particles. It has a rough surface and relatively uniform particle size. On the other hand, slag rapidly chilled by air consits mainly of spherical particles. It has a smooth surface and coarser particles. By crushing and grading the slag, it is possible to obtain fine aggregate with improved particle shape and size.

It should be noted that slag cooled by seawater or foul water is considered to have adverse effects on concrete and/or steel members used in concrete, hence is excluded from the scope of this Standard.

3. Classes

Slag fine aggregate can be singly used for fine aggregate in concrete. In practice, however, it is promissing that slag fine aggregate is often mixed with natural sand for improving gradation or some other purpose. In this light, this Standard provides for four classes of slag fine aggregate according to the particle size as shown Table 1. This classification by particle size reflects the particle sizes of fine aggregate that are most frequently used of late.

4. Quality

4.1 In the ordinary production process, it is unlikely that dust, dirt, organic impurities, salts, etc., which adversely affect the quality of concrete, enter slag fine aggregate. However, care should be exercised that those deleterious substances do not enter slag fine aggregate by way of the cooling water, air, etc.. Also, care should be exercised that foreign matter does not get mixed in slag fine aggregate during handling, transportation or storage.

4.2 The specifications in Table 2 reflect the following considerations:

(1) Calcium oxide

Unlike slag coarse aggregate produced from air-cooled slag, which contains calcium oxide (CaO) in the form of crystalline phase, as dicalcium silicate, slag fine aggregate produced from rapidly chilled slag contains calcium oxide in the form of glass phase, hence it is considered free from mineralogical unsoundness. It is generally believed that rapidly chilled slag may safely contain calcium oxide as much as 50%. As for expanded slag, which is a semi-rapidly chilled slag, JIS A 5002 (Light Weight Aggregate for Structural Concrete) specifies that the content of calcium oxide shall be a maximum of 50%. For extra safety, however, this Standard adopts the specifications in JIS A 5011 (Air-cooled Iron-Blast-Furnace Slag Aggregate for Concrete).

(2) Sulphur (total sulphur and sulphur trioxide)

Since sulphur contained in slag fine aggregate is dispersed in the glass phase of the rapidly chilled slag, it is considered more stable than that contained in air-cooled slag. Again, for extra safety, this Standard adopts the value specified in JIS A 5011.

(3) Total iron

Ferrous metal contained in slag fine aggregate may produce stains on the surface of concrete due to oxidation. Since it is extremely difficult to measure the content of ferrous metal accurately, this Standard specifies the content of total iron (as FeO). It may safely be said that a total iron content of 3% or less will virtually eliminate the fear of oxidation. The specified value of 3.0 max. is the same as in JIS A 5011.

(4) Physical properties

Of various physical properties, only oven-dry specific gravity, water absorption, and unit mass are specified in this Standard. In view of properties of blast furnace slag, the fine aggregate production process, and the present level of quality, it is considered unnecessary to specify other physical properties for slag fine aggregate. There are varieties of rapidly chilled granulated slag, from porous ones having small apparent specific gravity used as a material for portland blast furnace slag cement to hard, dense ones. It has been proved by many experiments that fine aggregate meeting the specifications for specific gravity and water absorption provided herein can safely be used for concrete.

4.3 The grading requirment has been specified for each class of slag fine aggregate. According to surveys of particle size distribution of slag fine aggregate actually produced, the fineness modulus is approximately 2.8 to 3.2 for 5 mm slag fine aggregate, approximately 2.5 to 2.7 for 2.5 mm slag fine aggregate, approximately 2.0 to 2.4 for 1.2 mm slag fine aggregate, and approximately 3.0 for 0.3 to 5 mm slag fine aggregate. These figures indicate that each class of slag fine aggregate can be designated as follows:

5 mm slag fine aggregate	Coarse sand
2.5 mm slag fine aggregate	Medium sand
1.2 mm slag fine aggregate	Fine sand
5 to 0.3 mm slag fine aggregate	For coarse sand for mixing (with fine sand)

As shown in Table 3, the gradings of the individual classes of slag fine aggregate notably overlap with on another. Actually, however, the abovementioned differences in fineness modulus permit clearout distinction among the different classes.

The particle size distribution of 5 mm slag fine aggregate is based on the standard grading specified by the Japan Society of Civil Engineers and the Architectural Institute of Japan (Class II aggregate), except that the mass percentage passing nominal sieve 0.15 mm is given greater margin, that is, 2 to 15%. This reflects the fact that the smaller the particle size, the greater becomes the specific gravity of slag fine aggregate as it contains internal pores, and that the more the fine particles, the better become the workability and the less the bleeding of concrete as the particle shape is somewhat angular.

4.4 Substantial variation in grading makes it difficult to ensure quality control of concrete. In this light, this Standard specifies the tolerance of fineness modulus to prevent excessive variances of grading for slag fine aggregate which is supplied or produced on a large quantity basis.

The tolerance of ±0.20 was determined taking into consideration the facts and figures about slag fine aggregate.

4.5 The problem of stability of slag fine aggregate during storage under high atmospheric temperatures is unique to slag fine aggregate. This Standard provides this section in response to requests for standardization of the stability. It should be noted that the stability of slag fine aggregate shall be confirmed by agreement between the parties concerned, since under certain working conditions the problem of stability may be ignored even in hot weather.

The test method for storage stability of slag fine aggregate described in Reference 2 was established by the working group of JIS Draft Preparation Committee for Blast Furnace Slag Fine Aggregate for Concrete after examinations of the relations with the agglomerating behavior of aggregate storage in hot weather, the results of indoor accelerated tests, etc..

The following describes the storage stability of fine slag aggregate. In hot weather, particles of slag fine aggregate are apt to cohere, hindering the outflow of the aggregate from the silo or bin in which it is stored. Experiences in the past indicate that this phenomenon begins to appear during the period when the average temperature is above 20°C (from the middle of May until the beginning of October in Japan, excluding Okinawa and Hokkaido). It is particularly conspicuous when the average temperature exceeds 25°C (from the beginning of July until the beginning of September in Japan).

Even slag fine aggregate whose storage stability will be judged to be 'b' by the test method described in Reference 2 can safely be used for the production of concrete if the slag fine aggregate is used immediately after it is produced. However, if the slag fine aggregate is to be stored for an extended period of time, it should be thoroughly mixed with natural sand or crushed sand in order to prevent cohesion of the aggregate. Alternatively, it is advisable to purchase slag fine aggregate whose storage stability is judged 'A' (less likely to cohere). According to the results of tests conducted during the period from the end of July to the end of August 1980, slag fine aggregates with judgment 'A' did not cohere after piling test for more than one month and those with judgment 'B' could be safely stored for at least 10 days from the date of production.

The following method of checking the condition of agglomeration of slag fine aggregate in aggregate storage can conveniently be used for storage control. This method consists of manually pushing a penetration resistance measuring instrument into the storage pile of slag fine aggregate. It is considered that slag fine aggregate whose penetration resistance coefficient is 0.45 or less can safely be used for the manufacture of concrete.

5. Tests

Samples to be tested shall be obtained in accordance with the applicable methods specified in JIS.

5.1 Chemical analysis

Chemical analysis shall be conducted in accordance with JIS A 5011, Section 5.1 (Method of sampling) and Appendix (Analytical Methods of Chemical Components of Blast Furnace Slag Aggregate).

It should be noted that instrumental analysis employing the fluorescent X-ray analysis methods, etc., can be effectively applied to daily quality control testing.

5.2 Tests for oven-dry specific gravity and water absorption

In addition to the slump cone procedure described in Section 3.3 of JIS A 1109 (Method of Test for Specific Gravity and Absorption of Fine Aggregate), various methods have been proposed to judge the saturated surface-dry condition of slag fine aggregate. These proposals have been discussed as pending problems. For example, the stainless steel plate method, improved stainless steel plate method, and direct shear machine method have been studied. Since these methods produce little difference in the result of testing, this Standard adopted the conventional slump-cone procedure.

It should be noted that for slag fine aggregate consisting of spehrical particles formed by rapid chilling by air, it is difficult and more erratic to judge the saturated surface-dry condition by slump-cone method. Only in this case, shall the method described in Section 3.3 (towel drying procedure to wipe water film from the aggregate particle surface) of JIS A 1110 (Method of Test for Specific Gravity and Absorption of Coarse Aggregate) be used instead of the method described in JIS A 1109, Section 3.3.

With slag fine aggregate containing substantial amounts of small particles, it is sometimes difficult to judge the saturated surface-dry condition. In this case, slag fine aggregate washed in accordance with JIS A 1103 (Method of Test for Amout of Materials Passing Standard Sieve 74 μm in Aggregates) may be used as a specimen.

6. Indications

Of the items to be indicated, 'date of manufacture' and 'other instructions for users' were provided from the viewpoint of quality assurance of storage stability at high temperatures. Namely, slag fine aggregate requires special consideration for storage stability during the period when the average temperature is above 20°C, although it is used in almost the same manner as crushed stone sand. The results of testing described in Reference 2 serve to judge the storage stability. In view of the fact that techniques to process slag fine aggregate to prevent its cohesion under high temperatures have been developed, there was opinion that it would be appropriate to indicate whether or not the slag fine aggregate was subjected to the processing. However, some slag fine aggregate have storage stability of 'A' grade even if they are not subjected to the processing. Besides, there is no fear of the cohesion of aggregate under low temperatures, regardless of whether the aggregate is subjected to the processing or not. In this light, this Standard specifies that the manufacturer who is supposed to have thorough knowledge of his products shall directly provide handling cautions (period of storage, etc.) based on the date of manufacture in order to permit the user to purchase the optimum product for the intended application.

Even when the average temperature is substantially low, slag fine aggregate may cohere if it is inadvertently added with an alkaline substance. It is safe to include such a seemingly well-known fact in the handling cautions.

REFERENCE 2. Explanation of Method of Testing Storage Stability of Slag Fine Aggregate

Introduction

The working group of the Technical Committee of Slag Fine Aggregate for Concrete conducted various tests on the cohesion of aggregate between 1978 and 1980, and eventually proposed the present test method.

Rapidly chilled granulated slag is a latent hydraulic material. Given an alkali stimulus, it tends to harden and cohere. When slag fine aggregate is stored for an extended period of time under high temperatures, particles may cohere even if no external alkali stimulus is given to the aggregate. The resistance against cohesion, or storage stability, varies from plant to plant manufacturing slag fine aggregate. This is considered due to the difference in solubility of slag fine aggregate itself, although some other factors still remain to be studied. The present test method determines the difference in storage stability of slag fine aggregate by accelerated test.

In developing the present test method, indoor tests were conducted under temperature between 20°C and 90°C. According to the test results, it took two to three days for slag fine aggregate samples to cohere under a temperature as high as 90°C. Although the autoclave processing performed as an accelerated test produced hydrates different from that produced by non-processed slag fine aggregate and the mechanism of cohesion differs from that under natural environments, a close correlation could be observed between the results of the autoclave processing and the results of field piling tests conducted on slag fine aggregate.

It is considered, therefore, that the reactivity of slag fine aggregate subjected to autoclave processing reflects the reactivity of slag fine aggregate in bulk storage with appreciable accuracy. In this light, this Standard adopted autoclave processing which procedures accelerated test results in only a few hours and is convenient for control and inspection.

It was proposed that changes in specific surface area, angle of repose, and orifice flowing time of slag fine aggregate, the amount of absorbed carbon dioxide, the pH value or calcium ion concentration of leaching liquid, etc., should be measured as criteria for the judgment of the ease (or difficulty) with which slag fine aggregate coheres. After comparative study of these, this

Standard adopted the mortar flow table testing method which can be closely related to field piling testing and is relatively easy to implement.

The validity of this testing method has been proved on slag fine aggregates which were processed and improved by various methods to make them less likely to cohere, as well as on ordinary slag fine aggregates of inherent storage stability.

1. Scope of Application

Since this test involves delicate elements, special care should be exercised in selecting the laboratory. The storage stability of slag fine aggregate depends on the characteristics inherent in the aggregate, and slag fine aggregate produced at the same manufacturing plant generally have uniform storage stability. Hence, this test shall not apply to daily control inspection.

2. Testing Equipment

2.1 Autoclave

This equipment is used to test the storage stability of slag fine aggregate under high temperature and high pressure (saturated steam pressure). It consists of the following devices:

(a) Exhaust valve
(b) Safety valve
(c) Pressure gauge
(d) Thermometer
(e) Pressure regulator
(f) Pressure vessel The pressure vessel shall have a working pressure resistance of 20 kgf/cm^2 {1.96 MPa}. From the view-point of heat resistance and durability, the vessel should be made of SUS 304 stainless steel or equivalent specified in JIS. The autoclave is a Class I pressure vessel defined by law: it must be tested and inspected to ensure safe operation.

2.2 Testing vessel

This Standard specifies that the testing vessel shall be a cylinder whose height is nearly the same as the diameter of the specimen so as to minimize the area of contact between the testing vessel and slag fine aggregate.

The testing vessel should be slightly tapered toward the bottom to facilitate the removal of the specimen after autoclave processing.

The testing vessel should be made of SUS 316 stainless steel or equivalent specified in JIS which ensures smooth inner surface and excellent durability. If the testing is infrequently performed, however, the testing vessel may be made of ordinary steel.

2.3 Testing vessel cover

3. Sample

3.1 Sampling

The sample shall be taken such that it represents the storage stability of the slag fine aggregate in question. Of the slag fine aggregates stored for some time after manufacture, some are in extremely active state as they are in the process of hydration and some are apparently very stable as the hydrate absorbs carbon dioxide from the air to form a calcium carbonate film on the surface. These slag fine aggregates may not indicate the true cohesion characteristics inhered in the aggregate itself. Thus, the sample of slag fine aggregate to be used for the test should be as fresh as possible. For this reason, this Standard specifies that the sample shall be taken from products within two days of manufacture.

The method of sampling is the same as used to collect samples of general aggregate. However, the sample should be taken from a depth of approximately 30 cm at least, where the aggregate is not exposed to the air.

During sampling or transportation of the sample, it is important to keep the sample from being exposed to the air. In this light, mixing with a shovel or dividing the sample into lots should be avoided as far as possible.

The reason why the sample should be taken at the plant where the aggregate is manufactured is that there seems a close relation between the number of days which elapse after the date of manufacture and the test results. Thus, if the test is entrusted to an outside organization or performed some time later, the sample should be preserved airtight at a temperature of 15°C or under, where hydration hardly occurs. When transporting the sample, it is convenient to use a portable ice-box.

3.2 Preparing sample

Measure the moisture content of the sample. Add purified water (distilled water or desalted water) to the sample to make the moisture content 10 ± 3%. This moisture content was selected taking into consideration the amount of moisture required for hydration and the optimum amount of moisture for compacting the sample determined based on the results of tests on the relation between moisture content and volume increase, or bulking of slag fine aggregate.

The moisture content should be measured speedily. For this purpose, an infrared moisture meter capable of measuring the moisture content of the sample in approximately 15 minutes or other suitable method can be used.

Preparation of the sample with a mixer should be completed within one to two minutes in order to minimize the exposure of the sample to the air.

4. Testing Procedure

4.1 Making test specimens

This Standard specifies that a mortar flow table widely employed for testing physical properties of cement shall be used to make test specimens because it is free from human error in compacting the sample. The mass per unit volume of test specimens becomes constant when the number of jigging motions exceeds approximately 70. Hence, for the purpose of this test, the number of 75 was selected.

4.2 Autoclave processing

Taking into consideration the test results of storage stability of slag fine aggregate stored under high temperatures in hot season for an extended period of time, the Standard specifies that the autoclave processing shall be performed at a gauge pressure of 15 kgf/cm^2 {1.47 MPa} held for two hours.

This gauge pressure corresponds to a temperature of 200.4°C. Hence, when the pressure is controlled by means of temperature, the temperature should be set to 200.4 ± 3.0°C.

It is necessary to previously confirm that the autoclave equipment can hold the pressure within the predetermined range.

If it is difficult to lower the pressure to a gauge pressure of 0.5 kgf/cm^2 {0.049 MPa}, (110.8°C) within 1.5 hours after the heater is stopped, the exhaust valve may be slowly opened to lower the pressure to the desired level. In this case, care should be exercised that the water tank of the autoclave equipment does not become empty. Thus, it is advisable to previously determine the required amount of water. In general, the amount of water equivalent to approximately 20% of the volume of the autoclave equipment is sufficient.

In taking out test specimens, special attention should be paid to safety. It is advisable to wear thick leather gloves when removing the autocalve cover. The outlet of the exhaust valve should be directed away from the operator. When removing the cover, it should be tilted such that the steam escapes from beneath the cover away from the operator.

4.3 Judgment test

(1) When taking the specimen out of the testing vessel, turn the vessel upside down to let the specimen come out by own weight. If the specimen does not come out by its own weight, tap the bottom of the vessel using care not to disturb the specimen. If the specimen still fails to come out, insert a spatula or wire between the vessel and the specimen to make a slightest gap so that the specimen can be taken out.

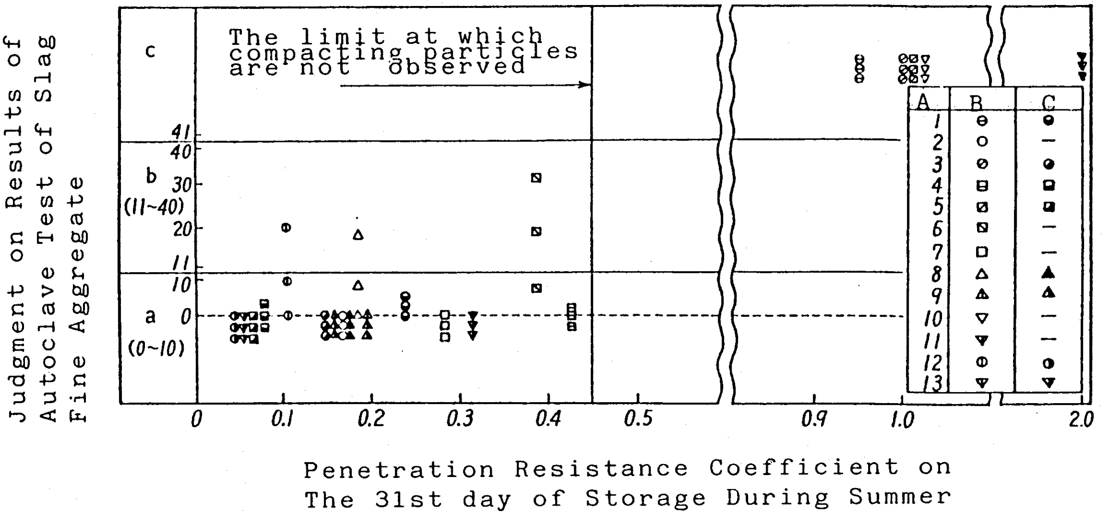
(2) If the specimen is compacted in lumps of a size of about 10 mm or greater, remove non-compacted particles with a brush, etc., allowing only compacted lumps to be placed on the mortar flow table. Then, jolt the flow table to permit the lumps to break to a size of 10 mm or less. Remove fine particles from the flow table using a brush.

5. Results and Judgment

Explanatory Figure 4 shows examples of results of this test and a piling test conducted in the summer of 1980. The results of this test represent the number of jigging motions required to break compacted lumps on the flow table, and the results of the piling test represent the values of the intrusion resistance test described in section 4.5 of the Reference.

According to the results of preliminary tests, those lumps which were broken on the flow table required 40 or less jigging motions. On the other hand, those lumps of slag fine aggregate which did not break after 40 drops proved to be unaffected by further drops, indicating that 40 drops are probably the limit of this break test based on dropping energy. Of fresh slag fine aggregates subjected to autoclave processing in accordance with this test procedure, those which broke within 40 drops by the flow table showed an penetration resistance coefficient of less than 0.45 in the bulk storage test conducted in the summer (from the end of July till the beginning of September, 1980) and were considered to have sufficient storage stability.

Thus, in order to ensure sufficient safety margin in the summary and judgment of this test, the results of this test are classified according to the number of jigging motions on the flow table as shown in Reference Table 1, and the results of three specimens are shown in Reference Table 2, taking into consideration the results of field piling test and other various factors involved in collection and preparation of samples.



Explanatory Fig. 4

Result of Storage Stability Test of Fresh Slag Fine Aggregate (Stored One Day after Manufacture) and 50 to 150 t Field Piling Test of The Sample (A: Brand, B: Not Processed, C: Processed)