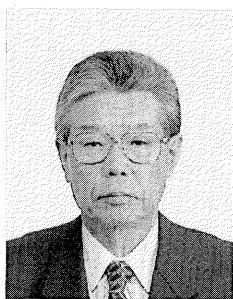


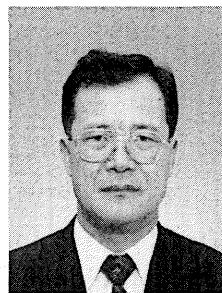
**RECOMMENDATION FOR CONSTRUCTION OF CONCRETE
CONTAINING FLY ASH AS A MINERAL ADMIXTURE**

(Translation from the CONCRETE LIBRARY No.94 published by JSCE, April 1999)

JSCE Research Committee on Fly Ash for Use in Concrete



Shigeyoshi NAGATAKI
Chairman of the Committee



Yukikazu TSUJI
Secretary of the Committee

Members of the Committee

Yoshinori IGASE
Toshiya KANOU
Tatsuhiko SAEKI
Yokito SUGIMURA
Touren TAKEUTI
Tsutomu FUKUTE
Toshiaki MIZOBUTI

Hiroyuki OHGA
Hirotaka KAWANO
Etsuo SAKAI
Kazuo SUZUKI
Isao NAGAYAMA
Tsuyoshi MARUYA
Yoshiki MURATA

Kazumasa OZAWA
Tatsuo KITA
Yoshihide SIMOYAMA
Makoto TAKADA
Makoto HISADA
Norihiko MIURA

Co-operating Member

Kazuo WATANABE

Members from Sponsoring Organization

Takashi ARAKAWA
Tadashi SUGI
Masashi NAKAI
Takeshi YAMAMOTO

Kunio OHTAKE
Morio TAKAHASHI
Toshimitsu HIRANO

Tsutomu KANAZU
Sigeru TSUTIDA
Kazuki MASUDA

SYNOPSIS

In recent years, much progress has been made in applying technologies of fly ash to concrete, and new higher levels of performance have been required. It was under such circumstances that in 1995 the Committee on Concrete of the Japan Society of Civil Engineers was requested by the Japan Association of Fly Ash to stipulating the Recommendation for Construction of Concrete Containing Fly Ash as a Mineral Admixture.

The Committee on Concrete, on accepting the request, established a Research Committee on Fly Ash for Use in Concrete in April 1995 and commenced investigations and studies in relation to this subject.

The Research Committee carried out various tests and studies to ascertain the practical natures of these concrete containing various types of Fly Ash as a mineral admixture, and using the results, stipulated "Recommendation for Construction of Concrete Containing Fly Ash as a Mineral Admixture" and the Committee on Concrete, upon carrying out deliberations, approved the Recommendation.

S. Nagataki is a professor of Department of Civil Engineering at Niigata University, Niigata, and a professor emeritus at Tokyo Institute of Technology, Tokyo, Japan. He received his Doctor of Engineering degree from the University of Tokyo in 1966. His research interests cover properties of high strength concrete, effective use of industrial by-products in concrete, durability of concrete. He is a fellow of ACI and JSCE and a member of JCI, JSMS, IABSE and RILEM.

Y. TSUJI is a professor of Department of Civil Engineering at Gunma University, Gunma, Japan. He received his Doctor of Engineering Degree from the University of Tokyo in 1974. His research interests include behavior of reinforced concrete structures, chemically prestressed concrete, and properties of fresh concrete. He is a member of JSCE, JCI, JSMS, ACI and IABSE.

RECOMMENDATION FOR CONSTRUCTION OF CONCRETE
CONTAINING FLY ASH AS A MINERAL ADMIXTURE

CONTENTS

CHAPTER 1 GENERAL

- 1.1 Scope
- 1.2 Definitions

CHAPTER 2 QUALITY OF CONCRETE CONTAINING FLY ASH AS A MINERAL
ADMIXTURE

- 2.1 General
- 2.2 Type and replacement ratio of fly ash
- 2.3 Strength

CHAPTER 3 MATERIALS

- 3.1 General
- 3.2 Fly ash
- 3.3 Cement
- 3.4 Chemical admixtures
- 3.5 Aggregates
- 3.6 Mineral admixtures other than fly ash

CHAPTER 4 MIX PROPORTIONS

- 4.1 General
- 4.2 Type and replacement ratio of fly ash
- 4.3 Water-binder ratio
- 4.4 Unit water content
- 4.5 Unit binder content
- 4.6 Sand-aggregate ratio
- 4.7 Air content
- 4.8 Dosage of admixtures
- 4.9 Form for expressing mix proportions

CHAPTER 5 PRODUCTION AND PLACING OF CONCRETE

- 5.1 General
- 5.2 Storage facility for fly ash
- 5.3 Batching of fly ash
- 5.4 Mixing
- 5.5 Transportation and placing

CHAPTER 6 CURING

- 6.1 General
- 6.2 Moist curing
- 6.3 Period of moist curing
- 6.4 Curing temperature
- 6.5 Accelerated curing

CHAPTER 7 READY-MIXED CONCRETE

- 7.1 General
- 7.2 Selection of concrete plants
- 7.3 Specification of qualities
- 7.4 Acceptance of supplied concrete

CHAPTER 8 QUALITY CONTROL AND INSPECTION

- 8.1 General
- 8.2 Quality control and inspection of materials
- 8.3 Quality control and inspection of construction

CHAPTER 9 MASS CONCRETE

- 9.1 Scope
- 9.2 General
- 9.3 Materials and mix proportions
- 9.4 Assessment of temperature cracking

CHAPTER 10 COLD WEATHER CONCRETING

- 10.1 Scope
- 10.2 General
- 10.3 Materials and mix proportions
- 10.4 Transportation and placing
- 10.5 Curing

CHAPTER 11 HOT WEATHER CONCRETING

- 11.1 Scope
- 11.2 General
- 11.3 Materials and mix proportions
- 11.4 Transportation and placing
- 11.5 Curing

CHAPTER 12 MARINE CONCRETE

- 12.1 Scope
- 12.2 Type and replacement ratio of fly ash
- 12.3 Concreting work

CHAPTER 13 PAVEMENT CONCRETE

- 13.1 Scope
- 13.2 Type and replacement ratio of fly ash
- 13.3 Strength
- 13.4 Concreting work

CHAPTER 14 DAM CONCRETE

- 14.1 Scope
- 14.2 Type and replacement ratio of fly ash
- 14.3 Concreting work
- 14.4 Quality control

CHAPTER 15 HIGH STRENGTH CONCRETE

- 15.1 Scope
- 15.2 Type and replacement ratio of fly ash
- 15.3 Production, placing, and curing

CHAPTER 16 SELF-COMPACTING CONCRETE

- 16.1 Scope
- 16.2 Materials and mix proportions
- 16.3 Production and execution

CHAPTER 17 CONCRETE PRODUCTS

- 17.1 Scope
- 17.2 General
- 17.3 Qualities of concrete
- 17.4 Type and replacement ratio of fly ash
- 17.5 Accelerated curing
- 17.6 Quality control and tests

CHAPTER 18 OTHER SPECIAL CONCRETES

- 18.1 General
- 18.2 Type and replacement ratio of fly ash

CHAPTER 1 GENERAL

1.1 Scope

(1) These Recommendations provide the general requirements for the construction of concrete structures made using concrete containing fly ash as a mineral admixture. As to matters not specified herein, the JSCE Standard Specification for Design and Construction of Concrete Structures 1996 (hereafter referred to as the “Standard Specification”) shall apply.

(2) The replacement ratio of fly ash shall normally be in the range of 10 to 30% of portland cement. When Type I fly ash is used, the upper limit may be raised to 40%.

[Commentary]

Regarding (1): These recommendations specify the general requirements for the construction of concrete structures made using concrete containing fly ash that conforms to JIS A 6201 (Fly ash for use in concrete). When using fly ash as a mineral admixture in concrete, the method of use and properties of concrete containing fly ash should be thoroughly understood before formulating a construction plan. The construction plan should be based on thorough examination of the mix proportions, production, and curing of such concrete to achieve the purpose of using fly ash, and the construction must be carried out according to the plan.

Fly ash is the pulverized ash collected with dust collectors from flue gases of a pulverized coal firing boiler. Extensive research has revealed that fly ash has, when mixed with concrete or mortar, the effects of (1) improving fluidity and permitting reductions in the unit water content, (2) reducing hydration heat, (3) increasing long-term strength, (4) reducing drying shrinkage, (5) improving watertightness and durability, and (6) inhibiting alkali-aggregate reaction. For this reason, it has been widely used as a mineral admixture for concrete and an addition in fly ash cement.

Though the use of fly ash was limited to large dam construction and prepacked concrete works in the first half of the 1950s in Japan, technologies to apply this to the cement and concrete field were then promoted, leading to the establishment of JIS A 6201 (Fly ash) in 1958 and JIS R 5213 (Fly ash cement) in 1960. Fly ash gradually found wider applications including general concrete structures, with its consumption increasing year after year. Accordingly, JIS A 6201 was revised in 1974 with changes mainly in the quality requirements to promote effective utilization of fly ash.

Though construction of thermal power stations later shifted to those based on combustion of petroleum or LNG for a certain period, the oil crisis of the 1970s led to the construction of a number of large-capacity coal-firing power stations from the standpoint of ensuring a stable supply of energy. The coal supply shifted from domestic coal to foreign coal, resulting in changes in the qualities of coal ash. However, JIS A 6201 remained as it was for approximately 20 years without review of the quality requirements.

Widening of the area of fly ash applications in the cement and concrete field to increase its use has become a pressing issue in the growing social trend towards global environment protection, such as the enforcement of the “Law for the Promotion of Utilization of Recycled Resources” in April 1991 to promote the effective utilization of coal ash as a designated byproduct,

In 1996, the title of JIS A 6201 was changed to “Fly ash for use in concrete” with revisions to parts of quality requirements and test methods to meet the social demand for the utilization of fly ash, as well as to adapt to the changing situation: (1) the source coal was shifting from domestic coal to foreign coal, and (2) it was necessary to put the test methods for fly ash qualities into line with the specifications of the International Standard Organization (ISO). In 1999, changes were made in the designations of fly ash types and quality requirements.

In the 1999 revision, fly ash was reclassified into four Types, I, II, III and IV, based on fineness and ignition loss.

Type I has a high fineness and low ignition loss. When used in place of part of portland cement, Type I fly ash significantly improves the fluidity of concrete and provides strength gains that match those of non-fly ash concrete. Type II is effective in restraining hydration heat of concrete, as well as in improving the fluidity of concrete and inhibiting alkali-silica reaction. Type III includes fly ashes with a high ignition loss. Though this type requires considerations to air entrainment and fluidity of concrete, it provides hydration heat-restraining, alkali-silica reaction-inhibiting, and strength-developing properties similar to Type II. Type IV with a low fineness requires

considerations to early strength development and fluidity of concrete, but it has a hydration heat-restraining property similar to Type II. This type also has an alkali-silica reaction-inhibiting effect similar to Type II, provided the replacement ratio is slightly increased. An air-entraining admixture for use with fly ash is recommended when using Type III and Type IV fly ashes. Type IV fly ash should be used for concrete requiring special considerations described in Chapters 9 through 18 as required.

The mixing properties, properties of fresh concrete, hydration and heat-generating properties, strength-developing properties, and durability of concrete containing fly ash as a mineral admixture vary depending on the type and replacement ratio of fly ash. Accordingly, an inadequate choice of a type and replacement ratio can cause failure to attain the required qualities or can lead to production of uneconomical concrete.

Fly ash to be used should as a rule be Types I, II, III or IV specified in JIS A 6201. The qualities of concrete containing fly ash substantially depend on the type, source, replacement ratio of fly ash, as well as the type and brand of cement, concrete placing temperature, and method and period of curing. It is therefore necessary to determine these factors adequately according to the purpose of using fly ash. Concrete containing fly ash particularly requires a longer moist curing period than concrete made using portland cement with no fly ash. An insufficient moist curing period not only nullifies the anticipated effect of fly ash but also can conversely impair the concrete quality.

In the case of concrete covered by the present Recommendations, the 1996 edition of the JSCE Standard Specification [Design] may be referred to regarding matters related to structural design. However, when using fly ash for a special concrete outside the scope of the present Recommendations or when adopting a replacement ratio exceeding the specifications of the present Recommendations, thorough examination from both aspects of design and construction should be carried out beforehand, referring to the present Recommendations and the 1996 version of the Standard Specification [Construction].

Regarding (2): Generally speaking, the effect of using fly ash may not be evidently appreciated with a replacement ratio of less than 10%. With a replacement ratio of Type II, III or IV fly ash exceeding 30%, special care is required for a number of processes including curing, and there have been few study results and field experiences to refer to in such a case. For this reason, the present Recommendations as a rule deal with fly ash replacement ratios between 10 and 30%. Nevertheless, replacement ratios exceeding 30% have actually been adopted overseas and for some structures including dams in Japan. Accordingly, it is not the intention of these Recommendations to prohibit the use of fly ash exceeding 30%. Such use is permitted, provided that sufficiently reliable construction is feasible. The upper limit was increased to 40% for Type I fly ash, as past studies have revealed that the effect of using fly ash is retained at such a high replacement ratio without any additional care during curing and other processes. The range of fly ash replacement ratios when used with blended cement is mentioned in the commentary under 3.3.

1.2 Definitions

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

Fly ash: Pozzolan ash collected with a dust collector from flue gases in a pulverized coal boiler.

Blend ratio: The percent ratio of the mass of fly ash contained in normal portland or blended cement to the total mass of the cement.

Combined ratio: The percent ratio of the total mass of fly ash added as a mineral admixture and fly ash preblended in normal portland or blended cement to the total mass of the binders. The term cement here includes those containing preblended additions.

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

Activity index: The percent ratio of the compressive strength of test mortar containing fly ash at a replacement ratio of 25% to the compressive strength of reference mortar made using normal portland cement tested in accordance with JIS A 6201, Appendix 2 (Code).

Flow value ratio: The percent ratio of the flow value of test mortar to the flow value of reference mortar tested in accordance with JIS A 6201, Appendix 2 (Code).

Fineness: The fineness of fly ash measured in accordance with the test methods stipulated in the text and Appendix 1 (Code) of JIS A 6201. This is expressed as a percentage retained on a 45- μ m sieve or specific surface area (cm^2/g).

[Commentary]

Fly ash is the ash collected at dust collectors as a residue from the combustion of pulverized coal burners transported through the boiler by flue gases in coal-burning power stations. Four types are specified in JIS A 6201 (Fly ash for use in concrete) primarily according to the combinations of fineness and ignition loss (see Table C1.2.1).

Regarding **blend ratio**: The blend ratio refers to the ratio of the mass of fly ash contained in cement in advance (see Fig. C1.2.1). JIS permits additions of up to 5% in total of fly ash, blast furnace slag, pozzolans, and pulverized limestone for clinkering to normal portland cement, singly or in combination. Also, fly ash contained in portland fly ash cement is specified to be more than 5% and not more than 10% for Type A, more than 10% and not more than 20% for Type B, and more than 20% and not more than 30% for Type C.

Regarding **combined ratio**: The combined ratio refers to the ratio of the total mass of fly ash added as a mineral admixture and preblended in cement as its constituent to the total mass of the binders (see Fig. C1.2.1).

Regarding **replacement ratio**: The replacement ratio refers to the ratio of the mass of fly ash used as a mineral admixture to the total mass of the binder (see Fig. C1.2.1).

Regarding **activity index**: The activity index refers to the degree of strength-developing property of concrete containing fly ash and is an important item of quality requirement indicating the performance of fly ash. For instance, a high activity index at an age of 7 days indicates a high early strength and high heat of hydration. Conversely, a low activity index indicates a low early strength and low heat of hydration. Though activity index is expressed as a ratio of compressive strength of mortar containing fly ash to that of mortar with no fly ash, it is correlated with the ratio of compressive strengths of concretes tested in the same way.

Regarding **flow value ratio**: The flow value ratio refers to the index to the degree of the fluidity development of concrete containing fly ash and is an important item of quality requirement indicating the performance of fly ash. The higher the flow value ratio, the lower the unit water content necessary for attaining the required fluidity.

Though flow value ratio is expressed as a ratio of flow values of mortars similarly to the activity index, it is correlated with the ratio of flow values of concretes tested in the same way.

Regarding **fineness**: The fineness of fly ash has a profound effect on the properties of concrete. Among the various methods of evaluating fineness, JIS A 6201 adopts the percentage retained on a 45- μ m sieve (mesh sieve method) and the specific surface testing (Blaine method).

Table C1.2.1 Types and qualities of fly ash

Fly ash type		Type I	Type II	Type III	Type IV
Item					
Silicon dioxide (%)		≥ 45.0			
Moisture content (%)		≤ 1.0			
Ignition loss ¹⁾ (%)		≤ 3.0	≤ 5.0	≤ 8.0	≤ 5.0
Density (g/cm^3)		≥ 1.95			
Fineness ²⁾	Part retained on a 45 μm sieve (mesh sieve method ³⁾ , %)	≤ 10	≤ 40	≤ 40	≤ 70
	Specific surface area (Blaine method, cm^2/g)	$\geq 5,000$	$\geq 2,500$	$\geq 2,500$	$\geq 1,500$
Flow value ratio (%)		≥ 105	≥ 95	≥ 85	≥ 75
Activity index (%)	28 days	≥ 90	≥ 80	≥ 80	≥ 60
	91 days	≥ 100	≥ 90	≥ 90	≥ 70

Notes: 1) The ignition loss values specified for the unburned carbon content measured in accordance with JIS M 8819 or JIS R 1603 may be adopted instead of the ignition loss measurements.

2) The fineness should be measured by the mesh sieve method or Blaine method.

3) When measuring the fineness by the mesh sieve method, the specific surface test results by the Blaine method should be indicated as a reference.

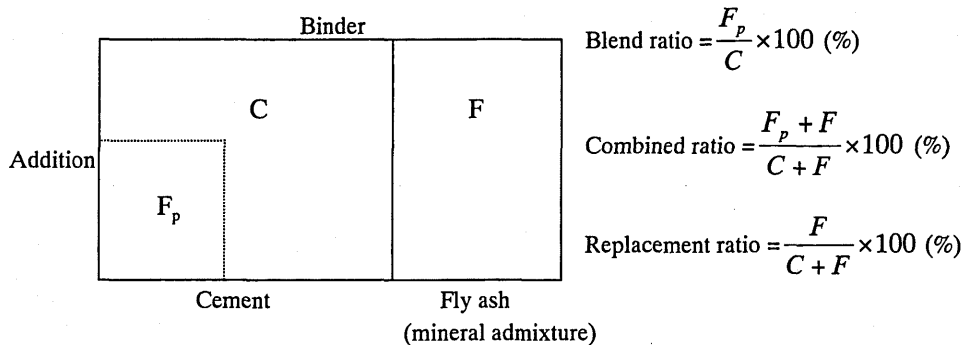


Fig. C1.2.1 Definitions of blend ratio, combined ratio, and replacement ratio

CHAPTER 2 QUALITY OF CONCRETE CONTAINING FLY ASH AS A MINERAL ADMIXTURE

2.1 General

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

[Commentary]

The properties of concrete containing fly ash differ somewhat from those of concrete without it. When using concrete containing fly ash, such properties should be thoroughly grasped to obtain the required qualities with minimum variation in quality.

The properties of concrete containing fly ash, mainly Type I and Type II, are described as follows:

Uniformity: Uniformity of concrete containing fly ash, which has a high dispersibility in concrete, can be ensured by a mixing procedure similar to that for concrete with no fly ash.

Fresh concrete: Fly ash improves the fluidity of concrete, as it generally consists of spherical fine particles. The unit water content of concrete containing fly ash therefore tends to be lower than that of non-fly ash concrete with the same slump.

Recently there have been increasing applications of self-compacting concrete whose workability is substantially improved by the use of mineral fine powder, air-entraining and high-range water-reducing admixtures, and segregation-inhibiting admixtures. Self-compacting concrete having adequate properties can be produced by selecting an appropriate type and replacement ratio of fly ash.

Since the use of fly ash tends to reduce the air content of concrete, a higher dosage of the air-entraining admixture is required to obtain the same air content. This is caused by unburned carbon in fly ash adsorbing the air-entraining admixture. It is therefore advisable, when using Type III or Type IV fly ash, to use an air-entraining admixture designed for use with fly ash.

Though the amount of bleeding water tends to be larger than that of non-fly ash concrete, a reduced unit water content to obtain a constant slump reduces the bleeding to a level similar to non-fly ash concrete.

The use of fly ash in concrete retards the setting, extending both initial and final setting times. It should be noted that the amount of bleeding water and setting of concrete containing fly ash are more sensitive to the as-mixed concrete temperature than those of concrete with no fly ash; a low temperature substantially increases bleeding and setting time.

Density: Though the density of fly ash is lower than that of portland cement, the effect of the difference is

relatively small. The density of concrete containing fly ash may be regarded as equivalent to that of concrete without it.

Strength: The strength development of concrete containing fly ash is strongly affected by such factors as the type and replacement ratio of fly ash and curing conditions. When fly ash is used in place of part of cement, the concrete strength generally decreases as the replacement ratio increases at early ages, but at later ages it becomes equal to or higher than the strength of concrete with no fly ash.

The strength development of concrete containing fly ash is more sensitive to the as-mixed concrete temperature and curing temperature than that of concrete with no fly ash is. The strength gains remain low for a long time particularly when the curing temperature is below 10°C. For this reason, special care should be exercised in curing where the curing temperature is below 10°C. Moreover, early drying tends to adversely affect the strength development of concrete containing fly ash. It is therefore necessary to ensure sufficient moist curing for such concrete.

The relationships between the compressive strength and the tensile and flexural strengths of concrete containing fly ash may be regarded as similar to those of concrete without it. The relationship between the compressive strength and Young's modulus may also be regarded as similar to that of non-fly ash concrete.

Thermal properties: The thermal properties of concrete containing fly ash depend on the type and replacement ratio of fly ash. The ultimate adiabatic temperature rise of concrete containing fly ash is lower than that of concrete made using normal portland cement with no fly ash. The temperature dependence of heat generation of concrete with fly ash is less evident than the case of normal portland cement without it.

Durability: Similarly to ground granulated blast furnace slag and silica fume, fly ash is known to have an effect of inhibiting alkali-silica reaction. A replacement ratio of any fly ash of 15% is generally effective in inhibiting alkali-silica reaction when the alkali content of cement is relatively low as is the case in portland cement produced in Japan and the alkali content of fly ash is around 4% or less.

Resistance of concrete containing fly ash to frost damage develops to the same level as that of non-fly ash concrete, if it is made as an air-entrained concrete and sufficiently cured. However, sufficient care should be exercised to protect the concrete from early frost damage, as pozzolanic reaction may not have sufficiently progressed and the hydrate structure may not be dense enough at early ages.

Pozzolanic reaction of fly ash reduces calcium hydroxide, lowering the pH value in concrete. This inhibits the formation of expansive hydrates and densifies the hydrate structure. Fly ash is therefore expected to improve the resistance of concrete to sulfates.

Watertightness: The watertightness of concrete containing fly ash can be lower than that of concrete without it for a few days at early ages, but attains the same or a higher level at a stage after 28 days when a sufficient strength is ensured.

Steel-protecting performance: The capability of concrete to protect steel encased in it is related to its resistance to oxygen and chloride ion penetration and to carbonation.

Among these, the use of fly ash is effective against penetration of chloride ions and oxygen. However, the expected resistance to chloride ions and oxygen may not be achieved under inadequate curing conditions that prevent sufficient progress of pozzolanic reactions.

Simple replacement of part of cement with fly ash slightly accelerates carbonation. However, factors affecting carbonation include the quality of the binder, as well as the water-binder ratio, environmental conditions of the structure, particularly the degree of wetness/dryness, and curing conditions. As the rate of carbonation is the same for concretes having the same 28-day compressive strength, concrete containing fly ash can be treated similarly to concrete without it in regard to carbonation, on condition that sufficient early curing is provided and that its water-binder ratio is not excessively high.

Shrinkage and creep: Drying shrinkage of concrete containing fly ash is generally smaller than that of concrete

without it, as the water-reducing effect of fly ash permits a reduction in the unit water content and its pozzolanic reaction densifies the hydrate structure. The shrinkage-reducing effect of fly ash is strongest when Type I fly ash is used.

According to recent studies, autogenous shrinkage, a phenomenon in which concrete shrinks due to hydration of cement, becomes evident when the water-binder ratio is low and can cause cracking. Though dependent on the type of cement and type and replacement ratio of fly ash, autogenous shrinkage is generally reduced by fly ash in place of part of cement.

The creep of concrete containing fly ash may be regarded as the same or lower than that of concrete without it. However, it is advisable to confirm the creep by testing, as there has not been sufficient experimental data regarding the early creep properties of concrete containing fly ash.

Color: Concrete containing fly ash can be slightly darker than non-fly ash concrete. Unburned carbon contained in fly ash can cause black spots on finished surfaces that are subject to bleeding.

2.2 Type and replacement ratio of fly ash

The type and replacement ratio of fly ash shall be appropriately selected so as to achieve the qualities of concrete required according to the purpose of using fly ash.

[Commentary]

As stated in the commentary of Section 2.1, concrete containing fly ash has various characteristics that are different from those of non-fly ash concrete. When using fly ash as a mineral admixture, it is important that the type and replacement ratio be adequately selected so that these characteristics can be fully developed.

The suitable type and replacement ratio of fly ash to be used are naturally limited to certain ranges according to the purpose of use. Table C2.2.1, which defines the recommended ranges of fly ash replacement ratios, may be referred to when selecting the type and replacement ratio of fly ash for each purpose.

Though the inclusion of fly ash as a mineral admixture may lead to various qualities of concrete depending on its type and replacement ratio, it is generally used to (1) improve fluidity, (2) restrain temperature rise due to hydration, (3) inhibit alkali-silica reaction, and (4) improve chemical resistance to sulfates and seawater.

When the primary purpose of using fly ash is to improve fluidity, a type with a low ignition loss and a high fineness is most effective. Only Type I and Type II are therefore listed in the table for this purpose. For the case where the restraint of temperature rise due to hydration is mainly intended, Type I with a high fineness is excluded from the list, as it can increase the thermal rate. When the inhibition of alkali-silica reaction is desired, all types of fly ash are included in the list as being effective, since they all exhibit pozzolanic reactivity. Where the major purpose is to improve chemical resistance to sulfates and seawater, Type IV is excluded, as its qualities are not expected to produce such an effect.

In addition, Types I and II are effective for self-compacting concrete, as they improve the fluidity of concrete. Type I also makes it easy to produce high strength concrete, as this type not only reduces the amount of bleeding water but also increases the strength gains.

Table C2.2.1 Types and replacement ratios of fly ash

Purpose	Type	Type I	Type II	Type III	Type IV
Improve fluidity		10-40%	10-30%	-	-
Restrain temperature rise due to hydration heat		-	20-30%	20-30%	20-30%
Inhibit alkali-silica reaction		15-40%	15-30%	15-30%	25-30%
Improve resistance to sulfates		10-40%	10-30%	10-30%	-
Improve resistance to seawater (incl. salt damage)		10-40%	10-30%	10-30%	-
Increase fluidity		20-40%	20-30%	-	-
Increase strength		10-30%	-	-	-

Note: This table gives the case of replacing part of normal portland cement with fly ash.

The replacement ratio should be confirmed by testing according to each purpose, as more than one purpose may be involved.

2.3 Strength

Generally, the strength of concrete containing fly ash as a mineral admixture shall be expressed by 28-day compressive strength of standard-cured specimens.

[Commentary]

The strength development of concrete containing fly ash is characterized by the strength gains sustained over a long period due to pozzolanic reaction, and the strength-developing behavior varies depending on the type and replacement ratio of fly ash. It may therefore be considered unreasonable from an engineering standpoint to adopt 28-day strength as the basis similarly to concrete without fly ash. However, 28-day compressive strength of standard-cured specimens was adopted as the basis for the strength of concrete for general structures, since it is not realistic to adopt a long-term strength as the basis for the strength of general structures.

According to the activity index values given in Table C1.2.1, the strength-developing properties of concretes containing Type I to Type IV fly ashes have the characteristics given below. However, strength development of concrete containing fly ash is also affected by the variations in the ignition loss and specific surface area by Blaine value. Thorough examination is therefore required when fly ash with little field experience is to be employed.

Type I: Nearly the same strength development as non-fly ash concrete is expected. Those having a higher CaO content particularly lead to higher strength gains.

Type II: Nearly the same strength development as non-fly ash concrete is expected up to an inclusion of 10%, but an inclusion of 10% or higher slightly retards the strength development.

Type III: The activity index is the same as Type II. The strength-developing properties are also the same as Type II.

Type IV: This is a type of fly ash with a lower activity index than other types, which suggests no activity contributing to strength development. However, the strength gains of concrete containing this type of fly ash are not so low as indicated by the activity index. This type includes fly ash that exhibits a strength-developing property similar to that of non-fly ash concrete despite its low fineness.

CHAPTER 3 MATERIALS

3.1 General

Materials to be used shall be of confirmed quality.

[Commentary]

When using fly ash as a mineral admixture for concrete, it is desirable to confirm not only the quality of each material but also the quality of concrete containing the material and fly ash, so that the intended effects can be fully realized. The qualities of concrete containing fly ash depend on the type and replacement ratio of fly ash, as well as the type of cement, placing temperature of concrete, and curing method. It is therefore advisable, when confirming the qualities of concrete, to produce trial mixtures applying the same materials, mix proportions, and construction conditions to be employed in the project.

3.2 Fly ash

- (1) Fly ash conforming to JIS A 6201 with uniform quality shall be used.
- (2) The ignition loss of fly ash to be used shall be within certain tolerances from the value at the time of establishing or modifying the proportions of concrete. When used with an air-entraining admixture or air-entraining and water-reducing admixture for general use, Type I and Type II fly ashes shall have an ignition

loss determined at the time of proportioning/re-proportioning ± 0.5 and ± 1.0 percentage points, respectively. When using an air-entraining admixture for use with fly ash, the tolerances may be widened to ± 1.0 and ± 1.5 percentage points for Type I and Type II, respectively.

[Commentary]

Regarding (1): JIS A 6201 (Fly ash for use in concrete) specifies the qualities of Types I, II, III, and IV according to combinations of fineness and ignition loss as given in Table C1.2.1 and stipulates the uniformity of fly ash quality in terms of tolerances from the fineness of the submitted sample. Since these quality requirements were established based on the results of surveys on actual fly ash qualities, the present Recommendation requires the use of fly ash conforming to JIS A 6201.

JIS A 6201 specifies the silicon dioxide (SiO_2) content, moisture content, ignition loss, density, fineness, flow value ratio of mortar, activity index, and uniformity of quality as the quality requirements of fly ash. These requirements are summarized as follows:

The silicon dioxide content of fly ash is required to be not less than 45% regardless of the type of fly ash. Fly ash has a property, the so-called pozzolanic activity, in which such components as amorphous silica are gradually combined at ordinary temperatures with calcium hydroxide resulting from cement hydration, forming insoluble and stable calcium silicate hydrates. The SiO_2 content is therefore regarded as a measure of judging the pozzolanic activity of fly ash. Other factors are also known to affect the pozzolanic activity of fly ash. These include the content of alumina (Al_2O_3) and other chemical components, ratio of vitrification, chemical composition of glass, and fineness.

Ignition loss, whose range is specified for each type of fly ash, is determined by subtracting the moisture content from the mass reduction after heating a sample to constant weight. The moisture content of all types of fly ash is required to be not more than 1.0% for the sake of easy handling including prevention of caking during storage. Also, since unburned carbon accounts for most of the ignition loss, JIS A 6201 permits that the ignition loss requirement is applied to, instead of the ignition loss, the unburned carbon content directly measured in accordance with JIS M 8819 (Coal and coke-Mechanical methods for ultimate analysis) or JIS R 1603 (Methods for chemical analysis of fine silicon nitride powders for fine ceramics). As unburned carbon contained in fly ash adsorbs air-entraining admixture, the air-entraining effect tends to be lower in concrete containing fly ash than in concrete without it, requiring a higher dosage of the admixture. This tendency is generally more evident with fly ash having a higher ignition loss. Also, a wide fluctuation of the ignition loss causes a fluctuation of the air content in the concrete. This results in fluctuations of the workability and strength, hampering the production of concrete with stable qualities. Particular care should therefore be exercised about the fluctuation of the ignition loss in fly ash. Other test methods as a guide to the air-entraining properties of fly ash include the test for the adsorption of methylene blue, which includes two methods: the standard method established by the Japan Cement Association (JCAS 1-61) and the specification by Electric Power Development Co. (draft). Another method of quality control is also proposed, which uses, as an index to air entrainment, the BET specific surface area of fly ash obtained by the nitrogen gas adsorption method. This is found to more evidently correlate with the air entrainment than the ignition loss or methylene blue adsorption.

The density of fly ash is required to be not less than 1.95 g/cm^3 , and the densities of most fly ash normally used fall in the range of 2.00 to 2.45 g/cm^3 . The density of fly ash tends to be affected by the component minerals, percentage of hollow particles frequently found among relatively large fly ash particles, and unburned carbon content.

As for fineness, JIS specifies the percentage retained on a $45\text{-}\mu\text{m}$ sieve and specific surface area. When the test for the percentage retained on a $45\text{-}\mu\text{m}$ sieve is selected, the report is required to include the specific surface area for reference. Generally speaking, the flow value ratio and activity index increase as the specific surface area of fly ash increases, leading to a strong effect of inhibiting alkali-silica reaction.

The flow value ratio is an index to the fluidity of fly ash expressed by the ratio of the flow of mortar, in which 25% by weight of normal portland cement is replaced with fly ash, to the flow of non-fly ash portland cement mortar, both with a water-binder ratio of 50%. The flow value ratio values of Types I, II, III, and IV are required to be not less than 105%, 95%, 85%, and 75%, respectively.

The activity index is a ratio of the compressive strengths of mortar containing fly ash to that of reference mortar having the same mix proportions as those used for the flow value ratio testing. This is specified for 28-day and 91-day strengths. The activity index is therefore a more direct index to the reactivity of fly ash than the silicon dioxide content. However, the strength-developing property of concrete containing fly ash depends not only on the activity index but also on such factors as the type of cement, replacement ratio of fly ash, aggregate, proportioning conditions, e.g., the water-binder ratio, and curing conditions. For this reason, it is desirable to examine beforehand the strength-developing property of concrete containing fly ash using trial mixtures while referring to the activity index, so that concrete having the required qualities can be obtained. The considerations should include the materials to be used for the project, construction conditions, and the conditions under which the structure is put into service.

Tolerances for the uniformity of fly ash quality are specified for each method of fineness evaluation. When evaluating the quality uniformity by the mesh sieve method, the percentage retained on a 45- μm sieve is required not to differ from that of the submitted sample by more than 5%. When evaluating by the specific surface area, the specific surface area is required not to differ from that of the submitted sample by more than 450 cm^2/g . The quality uniformity of fly ash must be ensured by either of these methods. Regarding the fineness values of submitted samples, the submitting and receiving parties are required to agree on matters including the values and effective periods with due consideration to the coal sources and state of operation at power plants.

Regarding (2): JIS A 6201 specifies the quality uniformity of fly ash only in terms of fineness. It is pointed out, however, that a wide fluctuation of the ignition loss of fly ash makes it difficult to exercise quality control, e.g., of air content, of concrete containing the fly ash, preventing ready-mixed concrete plants from producing concrete with uniform qualities. For this reason, the present Recommendation provides a permissible range of fluctuation of the ignition loss of fly ash to enable ready-mixed concrete plants to produce concrete with uniform qualities. The datum ignition loss should be the value used when determining or changing the mix proportions of the concrete, but can be modified according to the state of quality fluctuation of fly ash.

In concrete containing fly ash and an air-entraining admixture or air-entraining and water-reducing admixture for general use conforming to JIS A 6204 (Chemical admixtures for concrete), the tolerances for ignition loss are required to be ± 0.5 and ± 1.0 percentage points for Type I and Type II, respectively. When the fluctuation exceeds this range, replacement of the air-entraining admixture or air-entraining and water-reducing admixture with another type has to be considered. Air-entraining admixtures for use with fly ash have been developed in recent years with the aim of reducing the adverse effect of the fluctuation of fly ash ignition loss on the air-entrainment in concrete and reducing the time-related changes in the air content. These are specified in JSCE-D 107 (Standard specification for air-entraining admixtures for use with fly ash) (draft). This type of admixture facilitates the stabilization of the quality of concrete containing fly ash. Accordingly, the tolerances for the ignition loss of fly ash used with an air-entraining admixture for use with fly ash were widened to ± 1.0 and ± 1.5 percentage points for Type I and Type II, respectively. Type I and Type II fly ashes in which the ignition loss fluctuation is limited to ± 0.5 and ± 1.0 percentage points, respectively, may be subject to wider fluctuations on such occasions as the coal source changes in the power plant. In such a case, the quality of concrete containing fly ash can be easily stabilized by using an air-entraining admixture for use with fly ash.

The quality fluctuations of fly ash result from the changes of coal source and load conditions during power generation. Care should therefore be exercised, as drastic changes can occur over a long span of fly ash supply from a power plant. In the case where the average qualities of fly ash widely deviate, the quality of fly ash should be reviewed to take such measures as modification of mix proportions.

When producing air-entrained concrete containing Type III or Type IV fly ash, an air-entraining admixture for use with fly ash is recommended. However, no tolerances for ignition loss are made available for Type III and Type IV fly ashes in these Recommendations, due to insufficient data. When using Type III or Type IV, attention should be paid not only to the ignition loss but also to the fineness, calcium content, silicon dioxide content, and replacement ratio of fly ash, all of which affect hydration. Also, care should be exercised about the type and dosage of an air-entraining admixture, air-entraining and water-reducing admixture, or air-entraining admixture for use with fly ash to minimize the quality fluctuation of concrete containing fly ash.

3.3 Cement

- (1) Cement shall conform to JIS R 5210.
- (2) When using portland blast-furnace slag cement, portland pozzolan cement, and portland fly ash cement conforming to JIS R 5211, JIS R 5212, and JIS R 5213, respectively, the method of use shall be thoroughly examined.

[Commentary]

Regarding (1): All cements specified in JIS R 5210 (Portland cement) may be used for concrete containing fly ash. The properties of concrete made using normal portland cement can be relatively easily estimated, thanks to the large accumulation of study results and field experience. However, the effect of using fly ash can vary depending on the cement brand. It is therefore necessary, when no study results or construction records are available for reference, to produce trial mixtures using the cement, fly ash, and other materials to be used in the project to confirm the properties of the resulting concrete beforehand.

Other types of portland cements may be used when the required performance cannot be achieved with normal portland cement even after adjusting the proportions and fly ash replacement ratio or when the characteristics of cements other than normal portland cement are to be positively utilized. For instance, the use of high-early-strength portland cement is possible when a relatively high early strength is desired. Moderate-heat portland cement is effective where the possibility of cracking due to thermal stress induced by hydration heat should be minimized, such as in mass concrete and dam concrete. Also, a combination of fly ash and moderate-heat portland cement reportedly requires a lower dosage of an air-entraining and high-range water-reducing admixture than with normal portland cement to obtain the same fluidity of self-compacting concrete. Such a combination also produces stronger effects of increasing the fluidity, reducing the hydration heat, and reducing the drying shrinkage. When a greater reduction in the hydration heat is desired, one can adopt low-heat portland cement having a higher belite content than moderate-heat portland cement. When using portland cements other than normal portland cement, for which data accumulation has been insufficient, it is necessary to conduct tests beforehand to examine if these cements realize the intended effects while producing no adverse effects on other properties of the concrete.

Portland cements may contain additions of 5% or less. The effects of these additions may be neglected when selecting the replacement ratio of fly ash.

Regarding (2): When using blended cement, those conforming to JIS R 5211 (Portland blast furnace slag cement), JIS R 5212 (Portland pozzolan cement), and JIS R 5213 (Portland fly ash cement) should be used. However, there have been few examples of using these cements with fly ash. When part of these blended cements is replaced with fly ash, the quality of the resulting concrete may widely vary depending on the type of blended cement and type and replacement ratio of fly ash. A high blend ratio of blended cement, high replacement ratio of fly ash, or a high water-binder ratio could particularly extend the setting time, retard the early strength development, or increase the carbonation depth. They could also make the qualities of resulting concrete vulnerable to changes in the curing conditions. It is therefore necessary not only to confirm these properties by testing but also to examine the quality of concrete as a whole.

The upper limit of the fly ash replacement ratio in blended cement should be determined to ensure a portland cement content to supply fly ash and other additions with sufficient hydroxide ions and calcium hydroxide so that they can act as binders. The replacement ratio of fly ash added as a mineral admixture is generally expressed as follows:

- (1) In the case of portland fly ash cement

$$FR = \frac{R - F}{100 - F} \times 100 \quad (C3.3.1)$$

where FR = replacement ratio of fly ash (%)
 R = combined ratio of fly ash in the binder (%)
 F = blend ratio of fly ash preblended in the portland fly ash cement (%)

- (2) In the case of portland blast furnace slag cement and portland pozzolan cement

$$FR = R \quad (C3.3.2)$$

When blended cement is to be used, the upper limit of fly ash as a mineral admixture is determined as described below based on the maximum blend ratio specified in Section 1.1 (2) of the present Recommendations and current JIS for blended cement. Though a maximum replacement ratio of 40% is permitted for Type I fly ash, a

replacement ratio of 30% was adopted as the upper limit for Type I, similarly to other types, in consideration of the fact that fly ash additions in fly ash cement are not Type I and that concrete made using blended cement is strongly affected by the type and quality of the blended cement and the curing conditions.

- (1) In the case of fly ash cement

$$RF_A \leq \frac{30-F}{100-F} \times 100 \quad (C3.3.3)$$

where RF_A = upper limit of fly ash replacement ratio (%)

- (2) In the case of blast furnace slag cement

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

$$RF_A \leq \frac{30(70-S)}{70-0.3S} \quad (C3.3.4)$$

where S = blend ratio of ground slag preblended in portland blast furnace slag cement (%)

However, hydration of portland blast furnace slag cement partially replaced by fly ash has not yet been fully clarified. The present Recommendations, as a rule, adopt the following equation to be on the safe side as illustrated in Fig. C3.3.1.

$$\frac{S}{70} + \frac{RF_A}{30} \leq 1 \quad \therefore RF_A \leq 30(1-S/70) \quad (C3.3.5)$$

When the amount of an addition preblended in a blended cement is unknown, the maximum value specified in relevant JIS should be adopted.

Accordingly, the blend ratio or replacement ratio should be determined as follows:

In the case of fly ash cement, select a replacement ratio from Table C2.2.1 for normal portland cement of the present Recommendations according to the purpose of use and substitute it into Eq. C3.3.1 as the combined ratio, R , to determine the replacement ratio. Confirm that this replacement ratio does not exceed the value of RF_A in Eq. C3.3.3.

In the case of blast furnace slag cement, the replacement ratio should as a rule be determined based on experiments, observing the normal portland cement approach of selecting the replacement ratio according to the purpose of use given in Table C2.2.1 in the present Recommendations and referring to past data and records. Also, it should be confirmed that the selected replacement ratio does not exceed the RF_A value specified by Eq. (C3.3.5) or, when data and/or track records are available, Eq. (C3.3.4).

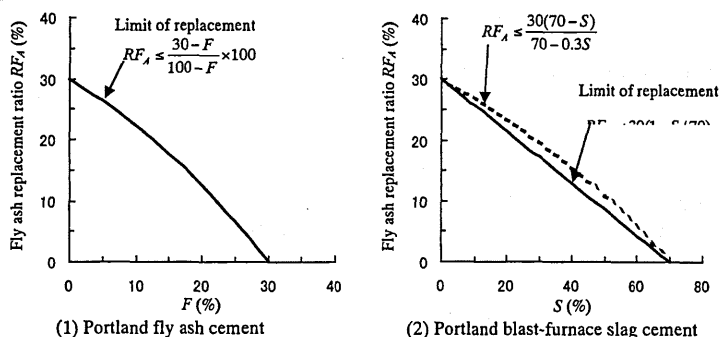


Fig. C3.3.1 Limits of fly ash replacement ratio when blended cement is used

3.4 Chemical admixtures

- (1) When using an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture, one that conforms to JIS A 6204 shall be used.
- (2) When using an air-entraining admixture for use with fly ash, one that conforms to JSCE-D 107 shall be used.
- (3) Corrosion inhibitors for reinforced concrete to be used shall conform to JIS A 6205. Superplasticizers, quick-setting admixtures, and anti-washout underwater admixtures to be used shall conform to JSCE-D 101, JSCE-D 102, and JSCE-D 104, respectively.
- (4) Chemical admixtures other than (1), (2), and (3) above shall be used after confirming their qualities and thoroughly examining the methods of using them.

[Commentary]

Regarding (1): In the case where an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture is used, these are required to conform to JIS A 6204 (Chemical admixtures for concrete).

It has been pointed out that one of the problems of concrete containing fly ash is the presence of unburned carbon in fly ash hindering air-entrainment. Since unburned carbon particularly adsorbs air-entraining admixtures, concrete containing fly ash may require a higher dosage of an air-entraining admixture for general use to ensure the required air content, or may undergo greater changes in the air content over time. These phenomena tend to be more evident as the fly ash replacement ratio increases. It is therefore necessary to confirm not only the quality of the admixture but also the properties of fresh concrete, such as air-entrainment and air content losses over time, when using an air-entraining admixture for general use. Unburned carbon can also adversely affect the working of water-reducing admixtures, air-entraining and water-reducing admixtures, and air-entraining and high-range water-reducing admixtures by adsorbing them. Accordingly, it is also necessary to confirm the performance of these admixtures beforehand using trial mixtures. An air-entraining admixture for use with fly ash is recommended when an air-entraining admixture for general use can hardly achieve the required air content or causes a large air loss over time.

Regarding (2): Air-entraining admixtures for use with fly ash were developed as admixtures that can be used at more constant dosages for wide fluctuations of unburned carbon content, while leading to smaller air losses over time, than normal air-entraining admixtures. These are required to be of the qualities conforming to JSCE-D 107 (Standard specification for air-entraining admixtures for use with fly ash) (draft). An air-entraining admixture for use with fly ash facilitates the production of concrete with more constant qualities than an air-entraining admixture for general use, improving the reliability of the quality of concrete containing fly ash. When using this type of admixture, it is necessary to confirm its quality, method of use, and effects in the concrete. Air-entraining admixtures for use with fly ash may not develop the required performance, if they are used with chemical admixtures other than those specified by the manufacturer and/or an air-entraining admixture for general use, or if sludge water is used as the mixing water. In such a case, instructions of the manufacturer should be observed, or the properties of the resulting concrete should be confirmed by testing. In such a case, instructions of the manufacturer should be observed, or the properties of the resulting concrete should be confirmed by testing.

Regarding (3): Corrosion inhibitors for reinforced concrete are required to conform to JIS A 6205 (Corrosion inhibitor for reinforcing steel in concrete). Superplasticizers, quick setting admixtures, and anti-washout underwater admixtures are required to conform to JSCE-D 101 (Standard specification for superplasticizers for concrete), JSCE-D 102 (Standard specification for quick setting admixtures for shotcrete) (draft), and JSCE-D 104 (Standard specification for anti-washout underwater admixtures) (draft), respectively. When using these admixtures, it is necessary to confirm that the intended effects fully develop when used with fly ash.

Regarding (4): No standard specifications are available for chemical admixtures other than (1), (2), and (3), and they are used in various ways. Most of them are not confirmed as fully developing their performance when used in combination with fly ash. Accordingly, when using a chemical admixture for which no standard specification is available, its qualities must be confirmed, and the method of its use and the properties of concrete containing it with fly ash must be thoroughly examined beforehand.

3.5 Aggregates

Fine and coarse aggregates shall conform to the Standard Specification [Construction].

[Commentary]

The availability of river aggregates, which are regarded as good aggregates, has been diminishing, as they are becoming exhausted and their use is restricted from the standpoint of environmental protection. This has led to the general use of crushed sand, sea sand, and land sand for fine aggregate and crushed stone for coarse aggregate. The social background of aggregates has also been changing in recent years, as blast furnace slag aggregate was standardized in JIS and recycled aggregate has been actively investigated. Since these aggregates mostly require a higher unit water content than river aggregates to attain the same slump, they generally tend to increase the drying shrinkage of concrete. Where the aggregate availability is low, aggregate exhibiting alkali-aggregate reactivity may have to be used.

On the other hand, good-quality fly ash replacing part of the binder is generally said to reduce the unit water content, improve the workability, reduce the drying shrinkage, and suppress alkali-silica reaction. Accordingly, fly ash is expected to improve the workability and reduce the drying shrinkage by reducing the unit water content where it is inevitable to use fine and/or coarse aggregates having relatively inferior grain shapes or fine aggregate having a low microparticle proportion. Appendix 6 (Code) "Method of suppressing alkali-aggregate reaction by cement selection" of JIS A 5308 (Ready-mixed concrete) permits the use of fine aggregate designated as "not innocuous" when it is inevitable, provided that fly ash is included at a replacement ratio of not less than 15%, which would produce the effect of inhibiting alkali-silica reaction. Therefore, when using fly ash as a mineral admixture, adequate use of fly ash in accordance with this also improves the properties while fresh and durability of the resulting concrete. Such use of fly ash is recommended from the standpoint of effective use of aggregate resources and environment protection as well. When using fly ash for the above-mentioned purposes, it is necessary to thoroughly confirm its effects beforehand by trial mixtures, as the effects may vary depending on the quality of aggregate, quality and replacement ratio of fly ash, and mix proportions of concrete.

3.6 Mineral admixtures other than fly ash

- (1) Ground granulated blast-furnace slag, expansive additives, and silica fume shall conform to JIS A 6206, JIS A 6202, and JSCE-D 106, respectively.
- (2) As for admixtures other than the above, their qualities shall be confirmed and methods of use thoroughly examined.

[Commentary]

Regarding (1): When using ground granulated blast-furnace slag, an expansive additive, or silica fume as a mineral admixture in combination with fly ash, these are required to conform to JIS A 6206 (Ground granulated blast-furnace slag for concrete), JIS A 6202 (Expansive additive for concrete), and JSCE-D 106 (Standard specification for silica fume for use in concrete) (draft), respectively. Ground granulated blast-furnace slag may be used with fly ash to produce high strength concrete, self-compacting concrete, or low-heat concrete. Silica fume may be used with fly ash to produce high strength concrete. An expansive additive may be used with fly ash to inhibit cracking induced by drying shrinkage or apply chemical prestress. However, the effects of these admixtures used in combination with fly ash may vary depending on the type and replacement ratio of fly ash, type and brand of cement, mix proportions of concrete, and curing conditions. It is therefore desirable to confirm the properties of the resulting concrete beforehand by testing.

Regarding (2): Mineral admixtures other than those mentioned in (1) are not covered by a JIS or JSCE standard. It is therefore necessary to confirm their performance before use by reliable data or testing. Also, even a mineral admixture that is generally known to exhibit high performance could behave differently depending on the type and replacement ratio of fly ash, type and brand of cement, mix proportions of concrete, and curing conditions. Accordingly, it is necessary not only to confirm the quality of the admixture but also to examine beforehand the properties of the resulting concrete, including the method of using the admixture, by testing.

CHAPTER 4 MIX PROPORTIONS

4.1 General

Mix proportions of concrete containing fly ash as a mineral admixture shall be established so as to minimize the

unit water content while ensuring the required strength, durability, watertightness, resistance to cracking, steel-protective capability, as well as adequate workability.

[Commentary]

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

4.2 Type and replacement ratio of fly ash

- (1) The type and replacement ratio of fly ash shall be adequately selected so that the purpose of using fly ash can be sufficiently fulfilled.
- (2) The fly ash replacement ratio shall as a rule be appropriately selected within a range of fly ash-binder ratio by mass of 10% to 30% (to 40% in the case of Type I).

[Commentary]

When using fly ash for concrete, one type should be selected from among Types I, II, III, and IV. An appropriate replacement ratio should also be selected, as a rule, within the range of 10% to 30% in terms of the percentage of the mass of fly ash in the total mass of the binders (to 40% in the case of Type I), so that the purpose of using fly ash is sufficiently fulfilled. Selections should be made in consideration of the descriptions in Sections 2.1, 2.2, and 3.2 of the present Recommendations.

The general flow to the selection of fly ash type and replacement ratio is shown in Fig. C4.2.1. When making selections, it is important to establish the type and replacement ratio suitable for the performance required of concrete to be used with a thorough grasp of the properties of fly ash. Since different types of fly ash produce different effects on the fluidity, strength development, and hydration-induced temperature rise of concrete, the type of fly ash should be determined according to the required performance of concrete. Also, it is important to confirm the adequate replacement ratio by testing and experimentation beforehand, as different types of fly ash

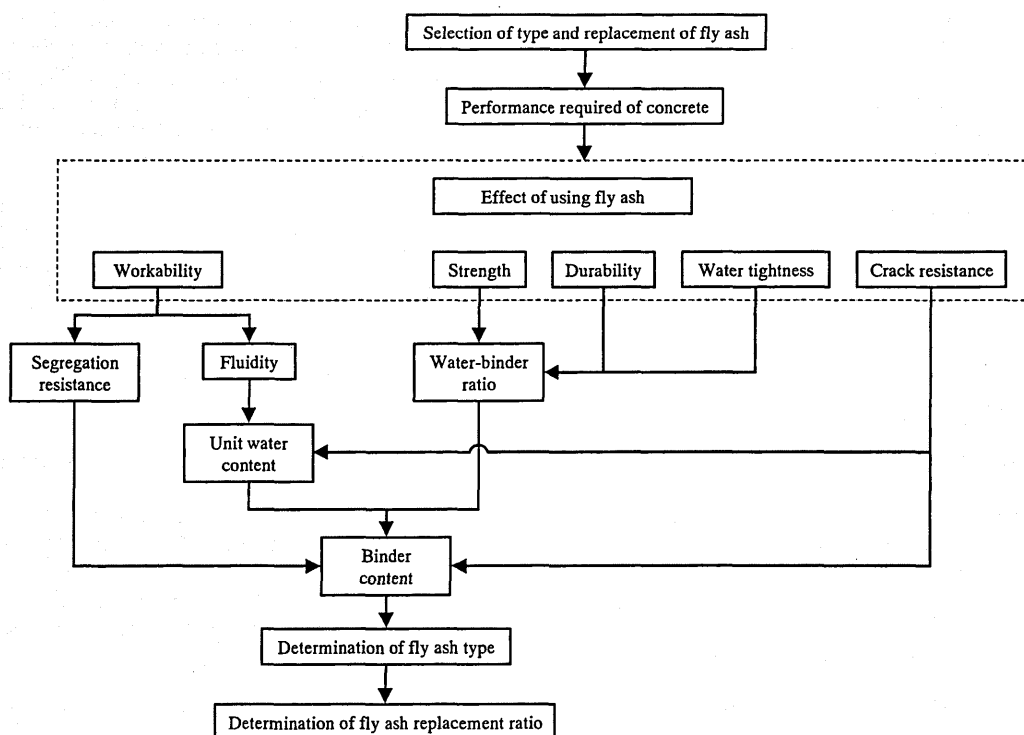


Fig. C4.2.1 General flow of selecting type and replacement ratio of fly ash

Table C4.2.1 Type and replacement ratio of fly ash according to purpose

Type	Replacement ratio (%)	Improve fluidity	Restrain hydration heat	Inhibit alkali-silica reaction	Improve sulfate resistance	Improve seawater resistance	Produce self-compacting concrete	Produce high strength concrete
I	10-15	○		△	○	○		○
	15-20	○		○	○	○		○
	20-30	○		○	○	○	○	○
	30-40	○		○	○	○	○	
II	10-15	○		△	○	○		
	15-20	○	△	○	○	○		
	20-30	○	○	○	○	○	○	
III	10-15			△	○	○		
	15-20		△	○	○	○		
	20-30		○	○	○	○		
IV	20-30		○	△				

Note: ○: desirable, △: acceptable

develop their full potentials in different ranges of replacement ratios.

Table C4.2.1 gives the desirable ranges of the type and replacement ratio of fly ash for the purposes of use, such as to increase fluidity, restrain hydration-induced temperature rise, and inhibit alkali-silica reaction.

With a high fineness, high activity index, and high flow value ratio, Type I fly ash causes concrete to have high fluidity and develop high strength. This type is therefore suitable for producing self-compacting concrete and high strength concrete. Appropriate replacement ratios for high fluidity and high strength are between 20 and 30% and between 10 and 30%, respectively. Type II has general characteristics of fly ash, such as to increase fluidity and restrain hydration heat. Accordingly, its replacement ratio should be selected according to the purpose of use. Though Type III does not increase fluidity, it causes the concrete to develop the same strength as Type II at a similar replacement ratio. As for Type IV, since its fineness, activity index, and flow value ratio are low, its replacement ratio should be determined by thoroughly examining the fluidity and strength development of the resulting concrete.

4.3 Water-binder ratio

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

- (1) The water-binder ratio shall not exceed 65%, as a rule.
- (2) When establishing the water-binder ratio, $W/(C+F)$, based on compressive strength of concrete, the value shall be selected as follows:
 - (a) The relationship between the compressive strength and the water-binder ratio shall as a rule be determined by testing. The standard test age shall be 28 days.
 - (b) The water-binder ratio to be used for proportioning shall be the inverse number of the binder-water ratio, $(C+F)/W$, corresponding to the proportioning strength, f'_{cr} , on the relationship line between the binder-water ratio and the compressive strength, f'_c . This proportioning strength shall be obtained by multiplying the design strength, f'_{ck} , by an appropriate factor. This factor shall be determined according to the variation coefficient of compressive strength of concrete expected at each construction site, and normally be the value obtained from the curve shown in Fig. 4.3.1.
- (3) In the case of establishing the water-binder ratio based on the resistance of concrete to frost damage, the water-binder ratio shall not exceed the values given in Table 4.3.1.

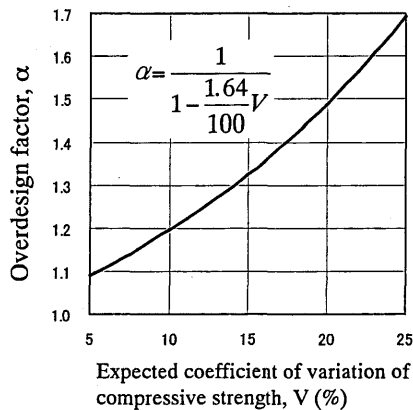


Fig. 4.3.1 Overdesign factor for general use

Table 4.3.1 Maximum water-binder ratio of air-entrained concrete containing fly ash when the resistance to frost damage is the determining factor (%)

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

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

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

Table 4.3.2 Maximum water-binder ratio of air-entrained marine concrete containing fly ash when the durability is the determining factor (%)

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

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

- (4) In the case of concrete to be used for marine structures, the standard maximum water-binder ratio determined from the durability shall be the values given in Table 4.3.2.
- (5) In the case of establishing the water-binder ratio based on durability against chemical attacks on concrete, the following method shall be employed.
 - (a) For concrete in contact with soil or water containing sulfate equivalent to SO_4 of 0.2% or more, the water-binder ratio shall not exceed the values given in Table 4.3.2 (c).
 - (b) For concrete on which the use of a deicing agent is expected, the water-binder ratio shall not exceed the values given in Table 4.3.2 (b).

[Commentary]

Regarding (1): In the case of establishing the water-binder ratio in consideration of the required strength, durability, watertightness, crack resistance, and steel-protective capability, a water-binder ratio of more than 65% tends to pose quality problems even when fly ash is used. A maximum water-binder ratio of 65% as a rule was therefore specified in the present Recommendations similarly to concrete with no fly ash.

Regarding (2) (a): Similarly to the case of concrete containing no fly ash, the compressive strength of concrete containing a fixed type and replacement ratio of fly ash has a linear relationship with the binder-water ratio. Accordingly, the water-binder ratio is required as a rule to be determined from the relationship between the compressive strength and the binder-water ratio of concrete containing fly ash of the selected type and replacement ratio. Refer to the Standard Specification [Construction] regarding the method of determining the relationship between the binder-water ratio and compressive strength. It should be noted that the standard age of testing compressive strength of concrete containing fly ash is 28 days similarly to concrete with no fly ash, though the compressive strength of concrete containing fly ash significantly increases after 28 days in most cases.

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

Regarding (3), (4), (5), and (6): Concrete containing fly ash exhibits the same or a higher resistance to frost damage, durability against seawater, durability against chemical attack, and watertightness than concrete with no fly ash at a stage after 28 days, when sufficient strength is attained, though they can be lower for a few days at an early stage. Also, numerous experiments and construction records have confirmed that, when sufficiently cured, concrete containing fly ash with a certain water-binder ratio has the same or higher strength than concrete containing no fly ash with the same water-cement ratio. This is because concrete containing fly ash forms a dense microstructure and because fly ash in place of cement reduces the amount of calcium hydroxide. Accordingly, where the water-binder ratio is established based on durability and watertightness, simple application of the water-cement ratio values of concrete containing no fly ash to the water-binder ratio of concrete containing fly ash is expected to lead to sufficiently durable and watertight concrete. The water-binder ratio is therefore required to be established in line with the values specified in the Standard Specification [Construction].

4.4 Unit water content

- (1) Unit water content shall be established by testing so as to be the lowest within the workable range.
- (2) When using an air-entraining and high-range water-reducing admixture, the unit water content shall as a rule be not more than 175kg/m^3 .

[Commentary]

Regarding (1): Slump of concrete should be minimized while maintaining concrete workability. The unit water content is required to be established based on tests using materials to be employed for the project, since the unit water content necessary to obtain the required slump varies depending on materials used and mix proportions. The Standard Specification [Construction] specifies the upper limit of concrete slump at the time of placing to be normally 12 cm. The recommended upper limits of unit water content corresponding to this slump value are specified as given in Table C4.4.1. These values should not be exceeded in the case of concrete containing fly ash as well.

Table C4.4.1 Upper limit of unit water content of concrete

Maximum aggregate size (mm)	Upper limit of unit water content (kg/m^3)
20-25	175
40	165

Though the unit water content necessary for attaining the required slump varies depending on the type and replacement ratio of fly ash, approximate values of unit water content when Type II is used at a replacement ratio of 20% are as given in Table C4.4.2. As shown in the table, the unit water content to attain the same slump is lower than concrete with no fly ash by 2 to 6% depending on the replacement ratio. The water-reducing effect of fly ash tends to increase as the fineness increases and the ignition loss decreases. Accordingly, the unit water content is further reduced by using Type I. When using Type III or Type IV, for which few construction records are available, the unit water content should be thoroughly examined by testing.

The adequate use of an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing

Table C4.4.2 Approximate values of unit coarse aggregate volume, sand-aggregate ratio, and unit water content of concrete

Maximum aggregate size (mm)	Unit coarse aggregate volume (%)	Air-entrained concrete				
		Air content (%)	With air-entraining admixture		With air-entraining and water-reducing admixture	
			Sand-aggregate ratio s/a (%)	Unit water content W (kg)	Sand-aggregate ratio s/a (%)	Unit water content W (kg)
15	59	7.0	46	173	47	163
20	63	6.0	43	168	44	158
25	68	5.0	41	163	42	153
40	73	4.5	38	158	39	148

- (1) These values apply to concrete containing Type II fly ash at a replacement ratio of 20%, sand with a normal grading (F.M.: 2.80) as fine aggregate, and crushed stone as coarse aggregate and with a water-binder ratio of 0.55 and a slump of about 8 cm.
- (2) Where the materials or qualities of concrete are different from those stated in (1) above, the values should be collected as given below:

Class			Correction of s/a (%)	Correction of W (kg)
For each 10 % point increase (decrease) in fly ash replacement ratio	Type	Type I	Reduce (increase) by 0.5 to 1.0 point	Reduce (increase) by 3 to 5 kg
		Type II	Reduce (increase) by 0.5 point	Reduce (increase) by 2 to 4 kg
For each 0.1 increase (decrease) in fineness modulus of sand			Increase (reduce) by 0.5 point	No correction
For each 1 cm increase (decrease) in slump			No correction	Increase (reduce) by 1.2%
For each 1% point increase (decrease) in air content			Reduce (increase) by 0.5 to 1 point	Reduce (increase) by 3%
For each 0.05 increase (decrease) in water-binder ratio			Increase (reduce) by 1 point	No correction
For each 1% point increase (decrease) in s/a			-	Increase (reduce) by 1.5 kg
Where river gravel is used			Reduce by 3 to 5 points	Reduce by 9 to 15 kg
Where crushed sand is used			Increase by 2 to 3 points	Increase by 6 to 9 kg

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

admixture, or air-entraining and high-range water-reducing admixture permits a substantial reduction in the unit water content. The water-reducing effects of these admixtures can be obtained in concrete containing fly ash similarly to non-fly ash concrete. However, the relationship between the admixture dosage and the resulting water-reducing effect may vary depending on the type and replacement ratio of fly ash to be used. It is therefore advisable to confirm the effect by testing. Also, certain types of fly ash may cause the slump to decrease as the replacement ratio increases. Accordingly, when it is difficult to obtain the required slump, it is advisable to ensure the quality by taking appropriate measures, such as modification of the proportions and the use of air-entraining and high-range water-reducing admixture.

Refer to Chapter 16 for determining the unit water content of self-compacting concrete.

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

4.5 Unit binder content

- (1) Unit binder content shall as a rule be determined from the unit water content and the water-binder ratio.
- (2) When a lower or upper limit is specified for the unit binder content, the limit shall be observed.

[Commentary]

Regarding (1): The unit binder content is required to be determined from the unit water content and the water-binder ratio established to provide concrete having the required strength, durability, watertightness, etc. The cement content and fly ash content are determined from this unit binder content and the fly ash replacement ratio.

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

4.6 Sand-aggregate ratio

The sand-aggregate ratio shall be established by testing so as to minimize the unit water content while ensuring adequate workability.

[Commentary]

Fly ash in place of part of cement increases the volume of the paste due to its lower density than cement. The sand-aggregate ratio can therefore be lower than that of concrete with no fly ash. For instance, a replacement by Type II at 20% can generally reduce the sand-aggregate ratio by about 1%. Type I with a higher fineness further reduces the sand-aggregate ratio. The sand-aggregate ratio and unit coarse aggregate volume given in Table C4.4.2 were determined by correcting the values given in Table C4.8.1 of the Standard Specification [Construction] in consideration of this point.

4.7 Air content

The air content shall be established based on testing to ensure the required value at the time of placing.

[Commentary]

When fly ash is used, unburned carbon contained in fly ash generally adsorbs air-entraining admixture, weakening and destabilizing their air-entraining effect. Since the unburned carbon content varies depending on the type and replacement ratio of fly ash, the dosage of the air-entraining admixture should be determined beforehand by testing to ensure the required air content. The air loss over time is larger than that of concrete with no fly ash, particularly in concrete containing Type III fly ash with a high unburned carbon content. It is therefore important to establish the as-mixed air content to ensure the required air content at the time of placing.

Certain types of fly ash at certain replacement ratios may not achieve the required air content with air-entraining admixtures for general use. In such a case, it is advisable to use an air-entraining admixture for use with fly ash developed to stabilize the air content in concrete containing fly ash.

4.8 Dosage of admixtures

- (1) The dosages of an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing admixture, and air-entraining and high-range water-reducing admixture shall be established by testing so as to provide the required slump, water-reducing effect, and air content.
- (2) The dosages of admixtures other than those mentioned in (1) above shall be established based on test results and field experience so as to provide the required effects.

[Commentary]

Regarding (1): The dosage of an air-entraining admixture to obtain the required air content tends to be higher than in concrete with no fly ash. This tendency becomes stronger as the fly ash replacement ratio increases and as its ignition loss increases.

Generally speaking, the ratio of a water-reducing admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture to the total binder content may be set the same as their ratio to cement content for concrete with no fly ash. In this case, it is advisable to confirm the effect beforehand by testing, since the water-reducing effect can vary depending on the type and replacement ratio of fly ash. Also, a

water-reducing admixture, air-entraining and water-reducing admixture, and air-entraining and high-range water-reducing admixture tend to retard the setting of concrete as the fly ash replacement ratio increases. Therefore their dosages should not be substantially increased.

Regarding (2): The effects of admixtures other than those mentioned in (1) above may vary depending on the type and replacement ratio of fly ash. Accordingly, their dosages should be established according to the proportions of concrete, construction conditions, and environmental conditions while conducting tests relevant to the purpose of using them or referring to past test data.

4.9 Form for expressing mix proportions

- (1) The specified mix proportions shall be generally indicated in the form shown in Table 4.9.1.
- (2) In the specified mixtures, fine aggregate is defined as entirely passing a 5-mm sieve, and coarse aggregate, entirely retained on a 5-mm sieve. Both aggregates shall be expressed in terms of their respective saturated surface-dry conditions.
- (3) When modifying the specified mix proportions into field mix proportions, the following shall be taken into account: water absorption of aggregate, percentage of fine aggregate retained on a 5-mm sieve, percentage of coarse aggregate passing a 5-mm sieve, and the quantity of water used to dilute chemical admixtures.

Table 4.9.1 Form for expressing mix proportions

Max. agg. Size (mm)	Slump (cm)	Air content (%)	Water-binder ratio W/(C+F) (%)	Replacement ratio F/(C+F) (%)	Sand-agg. ratio s/a (%)	Unit content (kg/m ³)							
						Water W	Binder		Fine aggregate S	Coarse agg. G		Admixture	
							Cement C	Fly ash F		mm to mm	mm to mm	Mineral admix.	Chemical admix.

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

[Commentary]

Regarding (1): Table 4.9.1 was established to indicate clearly the replacement ratio and content of fly ash based on the provisions of the Standard Specification [Construction].

CHAPTER 5 PRODUCTION AND PLACING OF CONCRETE

5.1 General

- (1) When producing concrete containing fly ash as a mineral admixture, the materials shall be adequately accepted, stored, weighed, and mixed using equipment having the required performance.
- (2) Adequate plans shall be formulated prior to transporting and placing concrete containing fly ash.

[Commentary]

Regarding (1): In order to produce concrete with the required qualities using fly ash, it is vital to fully recognize that fly ash is part of the binder and that its type and replacement ratio strongly affect the quality of concrete. It is therefore necessary to exercise control of the production sequence from material acceptance to mixing using equipment having the required performance, while employing fly ash having the required quality.

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

5.2 Storage facility for fly ash

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

[Commentary]

Requirements for fly ash storage facilities are basically the same as those for cement. Fly ash should be protected

from moisture, and venting should also be avoided during storage. It is recommended that their capacity be not less than three times the average daily need.

Fly ash should preferably be stored in a dedicated facility. Where shared use of a facility with cement, etc. is inevitable, fly ash should be stored after confirming the removal of the formerly stored material and thoroughly cleaning the place to avoid inclusion of cement, etc. in fly ash.

Also, fly ashes of the same type but from different sources generally possess different fineness and ignition loss. Handling them as having the same quality can adversely affect the mix proportions and qualities of the resulting concrete. The storage facility must be capable of accommodating fly ashes from different sources separately.

5.3 Batching of fly ash

- (1) The batching equipment for fly ash shall as a rule be dedicated to this purpose and shall be capable of weighing the quantity within the specified tolerances for batching errors.
- (2) Fly ash shall as a rule be weighed by mass for each batch of concrete.
- (3) Batching errors for fly ash shall not be greater than 2% for each batch.

[Commentary]

Regarding (1) and (2): Accurate batching of fly ash is one of the critical conditions of producing concrete containing fly ash. Fly ash forms a part of the binder and is a material by which the qualities of concrete are sensitively affected. An excessive batching error not only can cause failure to provide the required qualities of concrete but also could jeopardize the purpose of the entire structure made using this concrete. Accordingly, the use of dedicated batching equipment is required as a rule.

Where shared use of batching equipment for cement is inevitable, inspection must be carried out before batching fly ash to confirm that no cement remains in the equipment, so that no cement is included in fly ash. Cumulative batching of cement and fly ash using the same equipment is prohibited as a rule, since it can cause difficulty in maintaining the batching error of each material within the specified limits.

Regarding (3): The batching error is required to be not more than 2% similarly to normal admixtures in consideration of the fact that the fly ash replacement ratio is limited to 10 to 30% of portland cement (to 40% in the case of Type I) and that the effect of batching errors on the quality of concrete is similar to those of normal admixtures.

5.4 Mixing

- (1) Concrete materials shall be thoroughly mixed, so that uniform concrete can be obtained.
- (2) The sequence of charging materials into the mixer shall be appropriately established beforehand.
- (3) The mixing time shall as a rule be established by testing.

[Commentary]

Regarding (1): Concrete containing fly ash must be thoroughly mixed to disperse fly ash uniformly in the concrete.

Regarding (2): In order to disperse fly ash uniformly in concrete, it is advisable to place the discharge end of the fly ash bin near that of the cement bin and to charge fly ash into the mixer simultaneously with cement or immediately following cement.

Regarding (3): The mixing time necessary for obtaining uniform concrete varies depending on the type of mixer, mix proportions of concrete, type of mineral admixture, and sequence of charging the mixer. When establishing the mixing time by testing, it should as a rule be established by conducting tests for the variability of mortar density and variability of coarse aggregate content in concrete specified in JIS A 1119 (Method of test for variability of constituents in freshly mixed concrete), compression strength tests, air content tests, and slump tests specified in JIS A 8603 (Concrete mixers), and other tests as necessary.

In the case where no test is conducted for mixing time, minimum mixing times of 1.5 minutes and 1 minute by a gravity type mixer and revolving paddle mixer, respectively, may be regarded as standard, provided that the equipment in the plant is well-maintained.

5.5 Transportation and placement

- (1) Concrete shall be promptly transported after mixing, immediately placed, and fully consolidated. The time from the start of mixing to the completion of placing shall, as a rule, not exceed one and a half hours when the outdoor temperature is above 25°C and two hours when it is 25°C or below.
- (2) The concrete temperature at the time of placing shall as a rule be not lower than 10°C.

[Commentary]

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

Regarding (2): Strength development of concrete containing fly ash is strongly affected by the concrete temperature during hardening. If the concrete temperature at placing is low and if it falls below 10°C during curing, then the required strength may not be attained at early ages and later specified ages as well. The concrete temperature at the time of placing is therefore required, as a rule, to be not less than 10°C. In the case of such thin members as slabs and walls in particular, a low concrete temperature at the time of placing results in low hydration heat generation during hardening and a low temperature during curing, adversely affecting the development of long-term strength. Accordingly, attention should be paid in cold weather to temperature drop during transportation. In the case of mass concrete, the placing temperature requirement may be reduced to not lower than 5°C, provided that the concrete is adequately cured, since temperature rise due to hydration heat from hardening concrete is anticipated.

CHAPTER 6 CURING

6.1 General

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

[Commentary]

Utmost care should be exercised for curing of concrete containing fly ash, as its strength develops more slowly than that of concrete containing no fly ash, and therefore the qualities of concrete are strongly affected by the quality of moist curing. When subjected to drying at early ages, concrete containing fly ash may develop lower strength than non-fly ash concrete, even if it is maintained moist thereafter. Even if it satisfies the long-term strength requirement, it still deserves attention, as the durability tends to be reduced.

Strength development of concrete containing fly ash is also strongly affected by placing temperature and curing temperature. A low temperature leads to low strength gains. When placing concrete under low temperature conditions, particularly in thin members such as slabs and walls, it is necessary to ensure an adequate curing temperature by formulating a curing plan with due consideration to these points.

Table C6.1.1 Guide to necessary degree of curing by type and replacement ratio of fly ash

Type Replacement ratio (%)	Type I	Type II	Type III	Type IV
10-20	A	B	B	C
20-30	B	B	B	C
30-40	C	-	-	-

Note: Letters A to C denote the degree of curing of concrete containing fly ash. The degree of attention required for each degree is as follows:

A: Requires care similar to concrete made using normal portland cement.

B: Requires slightly greater care than for concrete made using normal portland cement.

C: Requires special care compared with concrete made using normal portland cement.

The degree of curing necessary for concrete containing fly ash to develop its full strength varies depending on the type and replacement ratio of fly ash. Table C6.1.1 can be referred to as a simple guide.

6.2 Moist curing

- (1) When curing concrete, moisture loss due to exposure to direct sunlight and/or wind shall be prevented. Exposed surfaces of concrete shall also be maintained wet throughout the curing period.
- (2) When concrete has hardened sufficiently to allow working without damaging the surfaces, exposed surfaces shall be maintained wet by being covered with a curing mat, wet cloth, or other materials, or by spraying or ponding for the rest of the curing period.

[Commentary]

Regarding (1): During curing, it is advisable to minimize moisture loss from surfaces in contact with sheathing as well by providing sheeting, etc., to protect them from sunlight and wind.

Regarding (2): When forms for walls, beams, columns, etc., are removed during the curing period, the exposed surfaces must be maintained wet.

The effect of membrane curing must be confirmed beforehand, as it may differ from that of normal moist curing.

6.3 Period of moist curing

The standard curing period of concrete made using normal portland cement, of which 20 to 30% is replaced with Type II fly ash, shall be extended by at least 2 days and 5 days at a daily mean air temperature of around 15°C and 10°C or lower, respectively, from that of concrete made using only normal portland cement under the same curing conditions.

[Commentary]

In order to enhance the strength and ensure durability of concrete, it is advisable to maintain concrete in a wet condition and ensure the longest possible curing period. Initial curing is particularly important for concrete containing fly ash, and the period during which the concrete is maintained wet should be longer than that for concrete made using normal portland cement without fly ash. It is therefore advisable that the period be established by thorough preliminary examination of the type and replacement ratio of fly ash, type of cement, proportioning conditions, such as water-binder ratio, type and location of the structure, climatic conditions the structure is exposed to, construction period, and construction methods. When determining the moist curing period from the aspect of the required concrete strength, it should be judged from the results of compression strength tests on concrete specimens cured under the same conditions as the concrete in the structure.

Fly ash with a higher fineness tends to lead to higher early strength gains, but fly ashes of the same type can exhibit slightly different strength-developing behavior after placing depending on their source and coal type. It is therefore advisable to grasp beforehand the strength-developing property of fly ash to be used by testing, etc. Nevertheless, arranging an excessively long curing period for an ordinary structure is uneconomical. As a standard for selecting a curing period, extra periods of at least 2 days and 5 days were adopted for a daily mean air temperature of 15°C and 10°C or lower, respectively, in the case of concrete made using normal portland cement, of which 20 to 30% is replaced with Type II fly ash. These extra periods should be added to the period specified for concrete made using normal portland cement with no fly ash. When using a different type and/or replacement ratio of fly ash, it is recommended that the necessary curing period be determined accordingly using Table C6.1.1.

At a temperature below 10°C, i.e., the lower limit of placing temperature, exposed surfaces of thin-sectioned members, for which little temperature rise of concrete is expected from hydration heat, should be maintained in a wet condition for a substantially long period. Also, maintaining concrete in a wet condition at low temperatures can cause frost damage even when the work is not classified as cold weather concreting. Accordingly, it is advisable that an adequate insulated curing or heat curing method be applied, which does not dry the concrete or cause cracking due to a wide temperature gap within the member.

When high-early-strength cement is used instead of normal portland cement, the period of moist curing may be shortened. However, great care must be exercised, such as examining the compressive strength of concrete

specimens cured in the same conditions as concrete in the structure.

6.4 Curing temperature

During the curing period, the temperature of concrete surfaces shall as a rule be maintained at 10°C or above.

[Commentary]

Low air temperature can cause delayed strength development and early frost damage of concrete containing fly ash, and this is not limited to the case of cold weather concreting. For this reason, it is desirable that the surfaces of concrete be maintained at 10°C or above during the curing period by heating or insulation with care to avoid their rapid drying. Care should be exercised particularly regarding thin members. In the case of mass concrete as well, it is desirable that the surfaces of concrete be maintained at 7°C or above. However, it is possible to use fly ash for mass concrete whose surfaces are expected to be below 7°C, on condition that thorough investigation is carried out beforehand.

The use of Type I fly ash mitigates the losses in strength gains caused by low curing temperature, yet it is also desirable in this case that insulated curing be done up to about 7 days.

There is a risk of cracking induced by temperature stress where an exceptionally high air temperature suggests a wide temperature gap between the inside and surfaces of concrete or where a large temperature rise is expected in mass concrete. In such a case, temperature rise or temperature differences should be restrained by such means as pipe cooling. When carrying out such temperature-controlled curing, the curing method and curing period must be adequately established with care to avoid rapid drying of concrete surfaces and giving consideration to the geometry and proportions of concrete to eliminate deleterious effects of temperature changes.

6.5 Accelerated curing

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

[Commentary]

When adopting steam curing, heat curing, and other accelerated curing to accelerate hardening of concrete, it is necessary to adequately establish the time to commence curing, heating rate, cooling rate, curing temperature, and curing period with thorough investigation into past examples. When using Type IV fly ash, particular care should be exercised, such as delaying the start of accelerated curing and extending the subsequent moist curing period.

CHAPTER 7 READY-MIXED CONCRETE

7.1 General

When ordering and using concrete containing fly ash as ready-mixed concrete, the concrete shall as a rule conform to JIS A 5308 in addition to the present Recommendations.

[Commentary]

JIS A 5308 (Ready-mixed concrete) specifies a number of requirements regarding materials, types, designations, quality, proportioning, production, quality control, test methods, and inspection methods. Ready-mixed concrete containing fly ash must generally meet these requirements. Since JIS A 5308 only provides fundamental rules applicable to ready-mixed concrete in general, it is advisable to establish matters not covered by JIS A 5308 before placing an order for ready-mixed concrete referring to Chapters 9 to 18 of the present Recommendations.

7.2 Selection of concrete plants

- (1) The suppliers' plant of ready-mixed concrete shall be selected from among JIS-accredited plants operated or controlled by personnel who are authorized by JCI as Chief Concrete Engineer or Concrete Engineer, or engineers who have knowledge and experience comparable or superior to them.
- (2) When selecting a plant, the following matters shall be taken into account: the storage facility for fly ash and other materials, batching equipment, availability of such apparatus as batching recorders, transportation time

to the site, unloading time, concrete production capacity, number of transportation vehicles, and state of quality control.

[Commentary]

Regarding (1) and (2): Fly ash is used in place of 10 to 30% (to 40% in the case of Type I) of cement in anticipation of its achieving the relevant purposes of using it, such as improving workability and restraining temperature rise due to hydration heat, as stated in Chapter 1. Constant production of concrete having the required qualities therefore becomes difficult unless storage and batching of materials and proportioning and mixing of concrete are adequately carried out. When placing an order for concrete containing fly ash as a mineral admixture, it is important to select a plant that is furnished with equipment necessary for producing such concrete and where strict quality control is exercised. It should also have permanently stationed engineers with sufficient knowledge and experience in the field of concrete. Accordingly, selecting a plant from among those JIS-accredited and operated and controlled by Class I or Class II concrete engineers or those having equivalent knowledge and experience is prescribed as a basic requirement when placing an order for ready-mixed concrete containing fly ash. However, the requirement of 7.2 (1) is not sufficient for concrete containing fly ash as a mineral admixture. The plant to be selected should be furnished with dedicated storage equipment to store fly ash under the same conditions as cement and equipment to batch it with the specified accuracy. It should also be accredited as having passed quality control audits conducted by the Federation of Ready-mixed Concrete Manufacturers of respective prefectures with an ability to carry out adequate quality control and shipment control. At the same time, it is desirable to select a plant equipped with a batching recorder that prints out the measurements so that the quantity of fly ash used can be confirmed.

7.3 Specification of qualities

When ordering a ready-mixed concrete containing fly ash, the purchaser shall specify the type of ready-mixed concrete, as well as type of cement, and type and replacement ratio of fly ash. The purchaser shall further specify the following items, where required, in consultation with the manufacture:

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

[Commentary]

Properties of concrete containing fly ash, including setting time and strength-developing property, vary depending on the type and replacement ratio of fly ash, type of cement, atmospheric temperature, etc. It is therefore important, when placing an order for concrete containing fly ash as ready-mixed concrete, to fully recognize this and adequately specify the type of cement and type and replacement ratio of fly ash in addition to the type of ready-mixed concrete.

In the case of concrete containing fly ash, a significant strength gain can normally be anticipated beyond 28 days. Accordingly, it may be economical for certain uses and fly ash replacement ratios to specify a later age to assure the nominal strength by consulting with the manufacturer while referring to Table C2.2.1.

Water-binder ratio and binder content are included in (e) "Other requirements."

Commercially available portland fly ash cement contains fly ash comparable to Type II fly ash as an addition, which is uniformly preblended with portland cement at cement plants. It is widely used and has numerous application records. For this reason, it may be convenient to consider first the use of portland fly ash cement where it can also ensure the required qualities.

7.4 Acceptance of supplied concrete

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

[Commentary]

As for preparation for acceptance of ready-mixed concrete, negotiation with the manufacturer, unloading points, and other matters of note, necessary requirements are provided in the chapter "Ready-mixed concrete" in the Standard Specification [Construction]. Since these are applicable as they are for concrete containing fly ash, an acceptance procedure is required to conform to the Standard Specification [Construction].

CHAPTER 8 QUALITY CONTROL AND INSPECTION

8.1 General

In order to ensure the required qualities of concrete containing fly ash, quality control and inspection of concrete materials and construction methods shall be exercised.

[Commentary]

Since the qualities of concrete containing fly ash vary depending on the type and replacement ratio of fly ash, placing temperature, and curing methods, quality control of concrete materials and concreting methods must be adequately exercised with a complete grasp of the properties of concrete to achieve construction relevant to the purpose of the structure. Inspection is defined as confirmation by the owner or an entrustee of the inspection that a concrete structure having the required qualities relevant to its purpose is being constructed under adequate quality control exercised at adequate stages of construction.

8.2 Quality control and inspection of materials

- (1) Quality control and inspection of fly ash shall be exercised in accordance with the Standard Specification [Construction].
- (2) Quality control and inspection of cement, mixing water, aggregate, and admixtures other than fly ash shall be conducted in accordance with the Standard Specification [Construction].
- (3) Should the quality of any material be judged inadequate by the inspection, appropriate measures shall be taken in accordance with the Standard Specification [Construction].

[Commentary]

Regarding (1): Quality control and inspection of fly ash should be exercised by confirming that the items specified in JIS A 6201 (Fly ash for use in concrete), i.e., silicon dioxide, moisture content, ignition loss, density, percentage retained on a 45- μ m sieve, specific surface area, flow value ratio, and activity index, satisfy the specifications. Quality control and inspection of other items are also recommended when deemed necessary.

The test method for an activity index to evaluate strength-developing properties requires the replacement ratio and water-binder ratio to be 25% and 50%, respectively. However, these may widely differ from the actual proportions. In such a case, direct evaluation of the strength under the relevant conditions may be recommended depending on the purpose of use.

Since the specific surface area and ignition loss have strong effects on the properties of fresh concrete and strength development, it is advisable to measure them at shorter intervals as necessary. Tests should be basically conducted in accordance with JIS A 6201. However, the quality of fly ash may normally be confirmed by the test report submitted by the manufacturing plant.

In order to produce concrete with constant qualities, the quality of fly ash should be constant. It is important to confirm not only the fulfillment of the quality requirements for fly ash but also the narrowness of the fluctuation range of fly ash quality, particularly in a large-scale project involving a large quantity of concrete.

Regarding (2): When an air-entraining admixture for use with fly ash is included, tests should be conducted in accordance with JSCE-D 107. However, its quality may be confirmed by the test report submitted by the manufacturing plant.

Air-entraining admixtures for use with fly ash may not develop the required performance when used with admixtures other than those specified or with normal air-entraining admixtures, or when reclaimed water is used as the mixing water. It is therefore advisable to confirm the performance of the air-entraining admixture for use

with fly ash beforehand using trial mixtures.

Regarding (3): The requirements of the Standard Specification [Construction] should be observed when exercising quality control and inspection of materials other than fly ash. Also, in case of nonconformity of any material to be used, the Standard Specification [Construction] should be referred to for remedial measures.

8.3 Quality control and inspection of construction

- (1) Quality control and inspection of production of concrete containing fly ash shall be exercised in accordance with the Standard Specification [Construction].
- (2) Quality control and inspection of concrete containing fly ash shall be exercised in accordance with the Standard Specification [Construction].
- (3) Quality control and inspection of transportation, placing, and curing of concrete containing fly ash shall be exercised in accordance with the Standard Specification [Construction].
- (4) Should concreting be judged inadequate by the inspection, appropriate measures shall be taken in accordance with the Standard Specification [Construction].

[Commentary]

Regarding (1): Concrete containing fly ash is produced at ready-mixed concrete plants or plants in construction sites. In either case, the production equipment and processes should be adequately controlled to ensure the production of concrete with the required qualities, similarly to the case of non-fly ash concrete. Accordingly, quality control and inspection of the production of concrete containing fly ash are required to be in accordance with the Standard Specification [Construction].

When concrete containing fly ash is produced, the characteristics imparted by fly ash are intended for the concrete, with the target performance being established. Accordingly, the attainment of the specified performance of resulting concrete must be confirmed by adequate control. When mixing concrete, it is important to confirm if the mixing is sufficient and if the specified quantities of components are mixed. Since the dispersibility of fly ash during mixing is relatively high, the required mixing time may be set the same as that of concrete with no fly ash. However, a slightly longer mixing time should be adopted in the beginning to allow for safety, and then an adequate mixing time should be established after confirming the quality stability.

Regarding (2): The performance items required for concrete containing fly ash and test methods for such items are basically the same as those for non-fly ash concrete. The quality control and inspection of concrete containing fly ash are therefore required as a rule to be in accordance with the Standard Specification [Construction].

When the replacement ratio of fly ash is established for a special purpose, such as to improve durability or reduce hydration heat, quality control should be exercised to maintain the specified replacement ratio over time, and inspection should be made accordingly to check if the intended quality is attained.

To confirm the uniformity and replacement ratio of fly ash in concrete, the following methods can be applied: "Simple test method of confirming mixing uniformity of fly ash as a mineral admixture (draft)" by the National Federation of Ready Mixed Concrete Industry Associations and JSCE-D 503 (Test method for replacement ratio of fly ash contained as a mineral admixture) (draft).

Though an early compressive strength is normally tested for exercising quality control based on compressive strength, early strength development of concrete containing fly ash as a mineral admixture is low, and the test results are strongly affected by fluctuations of the specimen temperature after molding and curing temperature. It is therefore important to establish the methods of producing and curing specimens taking account of these points. Several methods of judging concrete strength in a short time have been proposed. These methods provide the results in 1 hour at the earliest and 2 days at the latest after taking samples. However, these methods have been developed for non-fly ash concrete. When applying these methods to quality control of concrete containing fly ash, it is advisable to determine the correlation between early compressive strength and 28-day compressive strength beforehand or to conduct a 28-day compression test as well to confirm the attainment of the required qualities.

Regarding (3): Quality control and inspection of transportation, placing, and curing of concrete containing fly ash may be exercised similarly to the case of concrete with no fly ash. A transportation time is the time from the

beginning of concrete mixing to the end of placing. Its fluctuations cause changes in workability, resulting in fluctuations of concrete qualities. The transportation time must be within the specified length, and it is desirable to exercise control to minimize both the transportation time and its fluctuation. The method and period of curing are critical items to fully develop the properties of concrete containing fly ash. These items should therefore be adequately established in consideration of the type and replacement ratio of fly ash and weather conditions, and control should be exercised with care.

Regarding (4): When the concreting is judged inadequate by the inspection, appropriate measures must be taken in accordance with the Standard Specification [Construction].

CHAPTER 9 MASS CONCRETE

9.1 Scope

This chapter provides the general requirements for matters particularly necessary when fly ash is used as a mineral admixture for construction of mass concrete structures.

[Commentary]

Since the calorific value and thermal rate of concrete containing fly ash generally tend to be low, it is effective for mass concrete, in which thermal stress induced by hydration heat of cement is of concern, from the aspect of inhibiting thermal cracking. This chapter discusses the characteristics of concrete containing fly ash as a mineral admixture when applied to mass concrete with mentions of matters requiring special attention. This chapter does not cover dam concrete, as it is discussed in Chapter 14.

9.2 General

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

[Commentary]

Various measures are possible as crack-controlling methods for mass concrete, including inhibition of thermal cracking and limiting of locations and width of cracks, in the stages of design, material selection, proportioning, and execution. Among such measures, the use of fly ash with an adequate quality at an adequate replacement ratio is effective in inhibiting thermal cracking, as it reduces the calorific value and thermal rate. However, sufficient examination is necessary before using fly ash, as certain types and replacement ratios of fly ash, types of cement, and placing temperatures may delay the setting and retard early strength development, increasing the risk of cracking. Also, sufficient moist curing is necessary from immediately after placing.

9.3 Materials and mix proportions

Materials and mixture proportion of mass concrete shall be established so as to minimize the binder content and temperature rise of concrete while ensuring the required workability, strength, durability, watertightness, resistance to cracking, and steel-protective capability.

[Commentary]

Since the quality of cement and fly ash produces strong effects on the hydration heat generation of mass concrete, it is necessary to adequately select the type of cement and type and replacement ratio of fly ash so that concrete with the required qualities can be obtained.

Whereas fly ash in mass concrete mostly replaces up to 20% of cement (Table C2.2.1), a higher replacement ratio of up to 30% is also adopted, or moderate-heat portland cement is used instead of normal portland cement, with the aim of reducing the adiabatic temperature rise.

Due to their strong effect of restraining hydration heat generation, Types II, III, and IV fly ash are suitable for mass concrete structures. It should be noted that Type IV with limited field experience requires sufficient

preliminary examination. Ternary systems of cement containing ground slag or low-heat portland cement partially replaced with fly ash are also employed to reduce the temperature rise. Mass concrete should also be proportioned to minimize the binder content, while ensuring the required concrete qualities, since the calorific value of concrete is nearly proportional to its binder content.

Adequate use of an air-entraining and water-reducing admixture or air-entraining and high-range water-reducing admixture permits a reduction in the unit water content, thereby reducing the binder content. However, the setting time can be substantially extended depending on the type of chemical admixture and air temperature during placing. It is therefore necessary to confirm the degree of set retardation and effect on strength development.

Making the most of the high long-term strength gains of concrete containing fly ash, the binder content can be reduced by increasing the water-binder ratio while setting the age for design strength control beyond 28 days.

9.4 Assessment of temperature cracking

Temperature cracking of mass concrete shall be assessed by the method using the temperature cracking index.

[Commentary]

For structures involving mass concrete that requires control of temperature cracking or control of locations and width of cracks, the possibility of cracking should be assessed as follows: Calculate the temperature changes and thermal stress taking account of the materials and proportioning conditions, such as the type and replacement ratio of fly ash, type of cement, and binder content, construction methods, such as placing temperature and member thickness, and environmental conditions. Determine the temperature cracking index (tensile strength of concrete / maximum thermal stress within a member induced by hydration heat) based on the calculation, to assess the possibility of cracking. The methods of temperature analysis and thermal stress analysis to calculate the temperature cracking index should be in accordance with the chapter covering mass concrete in the Standard Specification [Construction]. However, the adiabatic temperature rise properties of concrete should be determined by testing as necessary, since it varies depending on the quality of fly ash, type of cement, binder content, and placing temperature.

CHAPTER 10 COLD WEATHER CONCRETING

10.1 Scope

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

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

[Commentary]

As described in the chapter covering cold weather concreting in the Standard Specification [Construction], setting and hardening of concrete may be substantially retarded and concrete can be frozen under weather conditions in which the daily mean air temperature is below 4°C. Since this tendency becomes more evident when fly ash is included in the concrete, cold weather concreting should be considered.

This chapter describes matters requiring special attention when concrete containing fly ash as a mineral admixture is applied to cold weather concreting.

10.2 General

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

[Commentary]

Concrete containing fly ash tends to be vulnerable to frost damage, due to its low early strength gains, as low

temperatures significantly retard its setting when compared with concrete with no fly ash. Measures should be taken to prevent this, such as selecting fly ash and other materials with suitable qualities, proportioning the materials adequately, controlling concrete temperature during transportation and placing, and carrying out temperature-controlled curing, e.g., insulated curing.

10.3 Materials and mix proportions

- (1) The type and replacement ratio of fly ash shall be adequately selected in consideration of their effects.
- (2) When using an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture as a chemical admixture, one conforming to JIS A 6204 shall be used as a rule.
- (3) When using an air-entraining admixture for use with fly ash, one conforming to JSCE-D 107 shall be used.
- (4) When using a superplasticizer, one conforming to JSCE-D 101 shall be used.

[Commentary]

Regarding (1): At low temperatures, concrete containing fly ash exhibits longer setting time and lower early strength development than non-fly ash concrete. This tendency becomes less evident when fine-grain fly ash is used, as the activity index increases as the fineness increases. It is therefore more advantageous for streamlined construction to select a type with a high fineness when using fly ash for cold weather concreting.

Regarding (2), (3), and (4): The use of an air-entrained concrete with an adequate air content for cold weather concreting is standard practice. This also applies to concrete containing fly ash. It is therefore required as a rule that concrete containing fly ash should contain an air-entraining admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture conforming to JIS A 6204 (Chemical admixtures for concrete).

In order to ensure adequate air content when producing concrete containing fly ash, it is effective to use an air-entraining admixture for use with fly ash specified in JSCE-D 107, which achieves the required air content relatively easily against fluctuations of fly ash qualities.

When using an anti-freezing admixture or cold-resistance admixture in addition to chemical admixtures indicated here, their quality must be confirmed by thorough examination of their components and effects.

10.4 Transportation and placing

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

[Commentary]

During concreting in cold weather, not only substantial retardation of setting and hardening but also freezing of concrete can occur when the air temperature rapidly drops. The concrete temperature should therefore be maintained at an adequate level during placing according to the structure size, weather, air temperature, and curing method. It is advisable to establish the concrete placing temperature in the range of 7 to 25°C and not widely different from the curing temperature. Table C10.4.1 gives the standard values of concrete placing temperature recommended for general cold weather concreting.

In the case of concrete containing fly ash as a mineral admixture, placing temperature should be slightly higher than that for concrete made of portland cement with no fly ash, as the hydration reaction is retarded and the thermal rate is low at low temperatures. The placing temperature of concrete containing fly ash as a mineral admixture should therefore be higher than the values given in Table C10.4.1.

Table C10.4.1 Recommended concrete placing temperature ranges

Temperature range	Member thickness	Thin	Normal	Thick
Lower limit (°C)		13	10	7
Upper limit (°C)		25	20	20

10.5 Curing

The curing temperature of concrete subjected to severe weather conditions shall as a rule be maintained above the lower limit of the concrete placing temperature range specified when formulating the construction plan until the compressive strength given in Table 10.5.1 is attained. When the specified compressive strength is attained during the curing period, concrete shall be maintained above the specified temperature for at least the following three days and above 0°C for two days thereafter.

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

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

[Commentary]

Concrete containing fly ash, when made into air-entrained concrete with an adequate air content, is known to be relatively resistant to frost damage under several cycles of freezing and thawing after attaining a compressive strength of 5 N/mm². When the compressive strength exceeds 10 N/mm², such concrete is said to resist deterioration due to freezing even in the case where wet concrete is continuously subjected to fierce meteorological action. The compressive strength values given in 10.5.1 were established based on this, in consideration of the effects of cross-sectional size of members and exposure conditions and in line with the standard compressive strengths required for non-fly ash concrete specified in the Standard Specification [Construction]. Even after the compressive strength is attained, concrete must be further cured above the specified temperature for at least 3 days and then maintained above 0°C for 2 days to be on the safe side and avoid rapid cooling of concrete. Needless to say, concrete must be cured until sufficient strength is attained to resist loading anticipated during construction.

The curing period required to obtain the strength given in Table 10.5.1 depends on such factors as the type and replacement ratio of fly ash, binder content, water-binder ratio, and curing temperature. Accordingly, this should be determined as a rule by the compressive strength of concrete specimens cured under the same conditions as the structure. It is advisable to confirm beforehand the curing period of concrete containing fly ash in place of part of portland cement in cold weather in terms of the number of days necessary for obtaining the required strength by producing concrete specimens with fly ash to be employed in the project.

CHAPTER 11 HOT WEATHER CONCRETING

11.1 Scope

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

When the construction is scheduled for the season or an area in which the daily mean air temperature exceeds 25°C, preparations shall be made for hot weather concreting.

[Commentary]

As mentioned in the chapter covering hot weather concreting in the Standard Specification [Construction], it is difficult to uniformly establish a period during which the requirements for hot weather concreting should be applied. Accordingly, hot weather concreting should be considered when concreting is scheduled for a time or place in which daily mean air temperature exceeds 25°C, as a high temperature of concrete adversely affects its quality while fresh and when hardened.

This chapter describes matters requiring special attention when applying concrete containing fly ash as a mineral admixture to hot weather concreting.

11.2 General

When using concrete containing fly ash for hot weather concreting, adequate measures shall be taken particularly for materials, proportioning, transportation, placing, and curing, to ensure the required qualities of concrete even under high temperature conditions.

[Commentary]

A high air temperature raises the concrete temperature, increasing the risk of slump losses during transportation and occurrence of cold joints, plastic shrinkage cracking, and temperature cracking. Though this tendency is basically the same as the case of using fly ash as a mineral admixture, fly ash generally retards the rates of hydration and setting of the binder as a whole when compared with the case of concrete made using normal portland cement with no fly ash. Concrete containing fly ash therefore reduces the above-mentioned risk and allows more time for transportation and placing even when Type III fly ash is used. From this aspect, it can be advantageous for hot weather concreting. In hot weather, however, concrete is subjected to rapid drying, and the degree of drying increases as the fly ash quality becomes lower. Care must be exercised in regard to this point when using concrete containing fly ash. In order to fully develop the effect of fly ash in hot weather concreting, it is necessary to take such measures as to select adequate materials and mix proportions, adopt adequate methods of transportation and placing, and carry out sufficient moist curing.

11.3 Materials and mix proportions

- (1) The type and replacement ratio of fly ash shall be adequately selected in consideration of their effects.
- (2) When using an air-entraining admixture, water-reducing admixture, air-entraining and water-reducing admixture, or air-entraining and high-range water-reducing admixture as a chemical admixture, those conforming to JIS A 6204 shall as a rule be used. The water-reducing admixture and air-entraining and water-reducing admixture shall be of the retarding type specified in JIS A 6204.
- (3) When using an air-entraining admixture for use with fly ash, one conforming to JSCE-D 107 shall be used.
- (4) When using a superplasticizer, a retarding type conforming to JSCE-D 101 shall be used.

[Commentary]

Regarding (1): The adiabatic temperature rise rate of concrete containing fly ash increases as the fineness of fly ash increases. Accordingly, the risk of temperature cracking should be considered when applying fly ash with a high fineness to hot weather concreting.

The slump loss over time of concrete containing fly ash is smaller in hot weather than that of concrete containing no fly ash. This permits a longer transportation time, leading to fewer cold joints. In order to make the most of this advantage, it is desirable to increase the fly ash replacement ratio to the highest practicable level between 20 and 30%.

Regarding (2), (3), and (4): Similarly to the case of concrete with no fly ash, the use of a retarding-type chemical admixture or an air-entraining admixture for use with fly ash is conceivable in hot weather as a measure to appropriately retard the setting and bleeding rates and reduce the slump loss of concrete containing fly ash.

When using flowing concrete containing fly ash for hot weather concreting, it is advisable to confirm beforehand the changes in slump over time even when a retarding-type superplasticizer is used.

11.4 Transportation and placing

Equipment and procedures for transporting and placing concrete shall be those that minimize drying and heating of concrete.

[Commentary]

In hot weather, concrete temperature can be readily increased during transportation in an agitating truck or conveyance in a mobile pump within the site, increasing the risk of placing difficulty and cold joints. Accordingly, measures should be taken to avoid excessive drying and heating of concrete during transportation and placing.

11.5 Curing

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

[Commentary]

Initial moist curing is particularly important in hot weather concreting to prevent rapid moisture loss and temperature rise due to sunlight of concrete after placing. Negligence of this process causes plastic shrinkage cracking. Also, concrete containing fly ash is vulnerable to excessive early drying, resulting in inadequate strength development at later ages. Sufficient moist curing is therefore necessary from this aspect as well. Moist curing must be started as soon as the exposed surfaces of concrete have become curable without damage.

CHAPTER 12 MARINE CONCRETE

12.1 Scope

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

[Commentary]

Marine concrete structures are gradually damaged by deleterious action, such as physical and chemical action of seawater, meteorological action, and friction and impact of waves and drift sand. Concrete used for marine structures is required to be durable and highly capable of protecting reinforcing steel.

Inclusion of fly ash in concrete reduces its hydration-induced temperature rise, increases its long-term strength, and reduces its drying shrinkage. In addition, it generally improves its resistance to seawater. Fly ash is therefore a material suitable for marine concrete.

The improvement in seawater resistance of concrete containing fly ash is reportedly attributed to the following phenomena:

- (a) Reduction in calcium hydroxide resulting from pozzolanic reaction of fly ash.
- (b) Densification of pore structure due to deposit of fly ash reaction products and reduction in permeability.

Densification of microstructure not only results from the inclusion of fly ash but also from the reduced unit water content necessary for attaining the required slump, i.e., the reduced water-binder ratio.

Underwater concrete is made as rich-mix concrete with a cement content of 370 kg/m³ or more to minimize segregation in water, and part of cement may be replaced with fly ash to increase the fluidity. Fly ash may also be used as a mineral admixture for grout mortar for prepacked concrete to increase the fluidity while controlling the hydration heat.

Whereas carbonation of concrete containing fly ash tends to proceed faster than that of non-fly ash concrete, carbonation under marine environment is slower than in air. Therefore carbonation generally poses no problem insofar as the requirements for cover depth in the Standard Specification [Design] are met.

On the other hand, concrete containing fly ash may be subjected to freezing and thawing in tidal and splash zones. It is therefore necessary to select an air-entraining admixture that ensures the required air content while minimizing the air loss in fresh concrete over time, as well as to carry out sufficient curing.

This chapter describes matters requiring special attention when using concrete containing fly ash as a mineral admixture for marine concrete.

12.2 Type and replacement ratio of fly ash

The type and replacement ratio of fly ash for marine concrete shall be selected to ensure the required qualities.

[Commentary]

Type I and Type II fly ash are recommended for marine concrete, and a replacement ratio of 10 to 20% should be regarded as a standard. It is advisable to use fly ash with the highest activity index available where the effect of seawater at early ages is of concern.

On the other hand, attempts have been made to use fly ash having a quality equivalent to Type III as a mineral admixture at a replacement ratio of 50% or more for underwater concrete to fill the gaps between foundation rubble and underwater structures. Also, a cement-to-binder ratio, $C/(C+F)$, of 15%, i.e., a fly ash replacement ratio of as high as 85%, has been adopted for producing cement structures for fish banks, though this is different from normal uses of concrete.

Accordingly, Type III fly ash or a replacement ratio of more than 20% may be sufficiently feasible, if the attainment of the required qualities is confirmed by testing, etc., depending on the environmental conditions and portions to which the marine concrete is applied.

12.3 Concreting work

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

[Commentary]

Concrete should be densified to reduce its permeability, in order to achieve sufficient resistance to reinforcement corrosion due to chloride ions in seawater and erosion of cement hydrates by salts (deterioration by seawater), which require particular attention in regard to marine concrete. When fly ash is contained as a mineral admixture, pozzolanic reaction proceeds along with the progress of cement hydration, contributing to the improvement in the resistance of concrete to seawater. Particularly careful curing is therefore essential when using fly ash for marine concrete, such as to protect concrete from seawater during the curing period and maintain the formwork, particularly sheathing, in place as long as practicable.

According to field experience of concrete made using fly ash cement, a curing period of at least 7 days is necessary.

CHAPTER 13 PAVEMENT CONCRETE

13.1 Scope

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

[Commentary]

The use of Type I or Type II fly ash for pavement concrete is expected to bring about such effects as reduced hydration-induced temperature rise, increased long-term concrete strength, and reduced drying shrinkage resulting from a reduced unit water content.

In addition to flexural stresses under traffic loading and cyclic stresses due to temperature changes, pavement concrete is subjected to harsh conditions, such as friction by tires, while being exposed to the elements for a long time. For this reason, concrete for pavement is required to have such performances as particularly high flexural strength, small drying shrinkage, low thermal during hardening, and low abrasion loss. Cement-treated base courses, which are covered with concrete slabs or an asphaltic concrete surface course, are protected from moisture loss, the elements, and friction while in service.

The use of fly ash as a mineral admixture is considered to provide concrete having the same or a higher performance than non-fly ash concrete to meet these requirements. The effect of using fly ash can be achieved particularly well in the case of cement-treated base courses.

For roller-compacted concrete paving using super-stiff concrete, fly ash suppresses segregation by the increased powder content in the concrete and improves the roller-compactibility by the ball-bearing effect. Accordingly, it permits an increase in the thickness of a rolling coverage.

This chapter describes matters requiring special attention when applying concrete containing fly ash as a mineral admixture to paving. For matters not specified in this chapter, the Standard Specification [Pavement] should be observed.

13.2 Type and replacement ratio of fly ash

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

[Commentary]

Type I and Type II fly ashes are recommended for pavement concrete, and a replacement ratio of 10 to 20% should be regarded as a standard. The use of fly ash other than Type I and Type II or a replacement ratio of over 20% is sufficiently feasible, provided that the attainment of the required qualities as pavement concrete is confirmed by testing, etc.

Type I fly ash is particularly suitable for pavement concrete under severe loading conditions, as it not only develops early strength but also ensures a high ultimate strength. In this case, it is necessary to determine an adequate replacement ratio by testing.

Fly ash replacement ratios of as high as 67 to 75% have been applied to roller-compacted concrete to increase the strength of base courses.

13.3 Strength

The flexural strength of standard-cured specimens at 28 days shall generally be regarded as the standard design strength of pavement concrete.

[Commentary]

The standard strength and control age for pavement concrete were established in line with the Standard Specification [Pavement]. A compressive strength may be presented as a standard for certain types of pavements.

Strength development is retarded when constructing a high strength base course using roller-compacted concrete with a high fly ash replacement ratio. In such a case, it may be more rational to adopt a control age later than 28 days for the design strength, taking account of the construction procedure for the base course and pavement, time to the traffic access, and strength development.

13.4 Concreting work

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

[Commentary]

When fly ash is contained, concrete requires particularly careful curing, as curing has stronger effects on the qualities of hardened concrete than on non-fly ash concrete.

As initial curing after finishing, covering must be provided until hardening to protect the concrete from direct sunlight and wind so that the concrete surfaces can be maintained moist. In the case of membrane curing, a curing compound must be uniformly sprinkled immediately before the water gleam disappears from the concrete surfaces and dries up after finishing. The coverage and sprinkling method of a curing compound must be thoroughly examined beforehand by testing, etc.

During the moist curing period, concrete should be constantly maintained moist and in an adequate temperature condition, and in addition, it should be protected from deleterious action of possible loading and impacts. In other words, when the concrete has hardened enough to permit work without damaging it, the concrete slabs should be maintained moist and in an adequate temperature condition by covering with curing mats or spraying water.

Moist curing should be continued until the flexural strength of concrete attains 70% of the proportioning strength. When no test is conducted, 21 days may be regarded as a standard curing period based on field experience of using fly ash cement. In the case of roller-compacted concrete pavement, this period may be reduced referring to application records, as load-bearing performance by interlocking coarse aggregate particles is anticipated.

CHAPTER 14 DAM CONCRETE

14.1 Scope

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

[Commentary]

Being a large-scale structure with great social importance, a dam must be designed, constructed, and controlled with meticulous attention to safety. It is therefore necessary to not only ensure the required density, strength, and watertightness but also to give careful consideration to long-range durability in the design and execution of dam concrete.

Fly ash is used in place of part of cement in most dam concrete, particularly roller-compacted dam concrete to control hydration heat of cement, which causes temperature cracking of concrete, and improve the workability of concrete.

This chapter provides a standard for matters requiring special attention when using fly ash for dam concrete as a mineral admixture. For general matters not specified in this chapter, the Standard Specification [Dam] should be observed.

14.2 Type and replacement ratio of fly ash

Type and replacement ratio of fly ash to be used for dam concrete shall be selected based on concrete tests using fly ash to be used in the project to ensure the required qualities of concrete.

[Commentary]

Four types of fly ash are specified in JIS A 6201 (Fly ash for use in concrete) according to the activity index, flow value ratio, fineness, and ignition loss. Fly ash having qualities equivalent to Type II have conventionally been used for dam concrete. However, Type III or Type IV fly ash can also be used for dam concrete, provided that attainment of the density, strength, watertightness, and durability required of dam concrete is ensured.

The qualities of fly ashes, such as fineness, ignition loss, density, silicon dioxide content, and moisture content, of the same specification may vary depending on their sources. It is therefore necessary to confirm the qualities of fly ash by concrete tests using fly ash actually used for the project.

Though good quality fly ash has the effects of improving the workability of concrete and restraining heat generation of concrete, an excessive replacement ratio adversely affects the early strength gains, resulting in failure to meet the design strength at 91 days. Accordingly, the replacement ratio of fly ash must be determined after confirming the attainment of the required qualities by concrete tests using the materials actually used in the project.

14.3 Concreting work

When using fly ash for dam concrete, concreting work shall be carried out with great care in regard to curing of concrete, as early strength gains of such concrete are particularly reduced in low temperature conditions.

[Commentary]

Early strength gains of concrete containing fly ash are low particularly at low temperatures. Concrete containing fly ash should therefore be protected by adequate curing during early ages. Also, great care should be exercised when adopting a fly ash replacement ratio of 30% or more or using Type III or Type IV fly ash, as these can delay the time of green cutting and form removal, adversely affecting the construction procedure.

14.4 Quality control

When using fly ash as a mineral admixture, quality control tests shall be regularly conducted to confirm the qualities of fly ash and their uniformity.

[Commentary]

The qualities of fly ash strongly affect the qualities of concrete while fresh and after hardening. For this reason, when using fly ash as a mineral admixture, it must be constantly confirmed that the fly ash qualities satisfy the quality requirements specified at the time of proportioning design and that the fluctuation of fly ash qualities is within the tolerances established at the time of planning and designing.

CHAPTER 15 HIGH STRENGTH CONCRETE

15.1 Scope

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

[Commentary]

General requirements for matters particularly necessary for design and construction of high strength concrete are provided in JSCE Recommendations for Design and Construction of High Strength Concrete Structures (Draft) and JSCE Recommendations for Design and Construction of Concrete Containing Silica Fume (Draft). This chapter describes matters requiring special attention when using fly ash for high strength concrete as a mineral admixture.

15.2 Type and replacement ratio of fly ash

The type and replacement ratio of fly ash for high strength concrete shall be selected so that concrete with the required qualities can be obtained.

[Commentary]

Type I fly ash with a high fineness, which is generally expected to improve the fluidity of concrete, should as a rule be used when using fly ash for high strength concrete.

The replacement ratio of fly ash should be determined by testing so that concrete with the required qualities can be obtained. It is reported that, with a replacement ratio of around 20%, the 28-day compressive strength of concrete containing fly ash is nearly the same as that of concrete with no fly ash.

Fly ash included in high strength concrete has an effect of inhibiting temperature cracking, as it reduces autogenous shrinkage and drying shrinkage, as well as hydration-induced temperature rise.

It is advisable to select the chemical admixtures and proportion the concrete based on testing, since the compatibility of fly ash with chemical admixtures and the time-related slump and air losses of the resulting concrete may vary depending on the fly ash sources.

15.3 Production, placing and curing

- (1) When using fly ash for high strength concrete, particularly the mixer, batch size and mixing time shall be selected adequately so that concrete can be thoroughly mixed.
- (2) When using fly ash for high strength concrete, particular care shall be exercised in regard to curing so as to prevent deleterious cracking.

[Commentary]

Regarding (1): Since high strength concrete has a higher binder content and lower water-binder ratio than normal concrete, the mixer type, batch size, and mixing time should be adequately selected to ensure thorough mixing. Insufficient mixing not only can produce nonuniform concrete but also could hamper the attainment of the required strength.

Regarding (2): When fly ash is included, the strength development and qualities of hardened concrete become more sensitive to curing. In the case of concrete with a low water-binder ratio, such as high strength concrete, drying of concrete surfaces after placing causes plastic shrinkage cracking. Also, a low as-mixed temperature

and/or early drying can inhibit early strength development, leaving little prospect of large long-term gains. Accordingly, it is more important than in the case of normal concrete to protect high strength concrete from drying immediately after placing and do sufficient moist curing during the early stage according to an adequate curing plan, in order to achieve the required qualities after hardening.

CHAPTER 16 SELF-COMPACTING CONCRETE

16.1 Scope

This chapter provides the general requirements particularly necessary when fly ash is used as a mineral admixture for self-compacting concrete.

[Commentary]

Self-compacting concrete is defined as “self-filling concrete having significantly improved fluidity and retaining the segregation resistance intact while fresh.” Self-compacting concrete is roughly classified into three types: powder type, combination type, and viscosity agent type. Self-compacting concrete containing fly ash is designated as either a powder type or a combination type. General requirements for self-compacting concrete are provided in JSCE Recommendations for Self-compacting Concrete. This chapter describes matters requiring special attention in regard to binary-system self-compacting concrete in which part of cement is replaced with fly ash.

16.2 Materials and mix proportions

- (1) Mix proportions of self-compacting concrete shall be adequately selected so as to provide the required fluidity, segregation resistance, strength, durability, watertightness, resistance to cracking, and steel-protective capability.
- (2) When using fly ash for self-compacting concrete, the type and replacement ratio of fly ash and the type of chemical admixtures to be used shall be adequately selected so that concrete with the required qualities can be obtained.

[Commentary]

Regarding (1): Self-compacting concrete should be proportioned to provide not only the required fluidity and segregation resistance but also the required strength and durability. The materials and mix proportions should therefore be selected in consideration of these qualities as a whole.

Regarding (2): Type I and Type II fly ashes are desirable for self-compacting concrete. Fly ash with a finer particle size and lower ignition loss can produce concrete with a lower unit water content. Also, fly ash with a finer particle size requires a higher dosage of an air-entraining and high-range water-reducing admixture or superplasticizer to ensure the same air content. Type I and Type II with fine particle size, which contribute to the improvement in the fluidity, are recommended as fly ash for self-compacting concrete, since the fluidity of concrete is predominantly affected by the particle size of fly ash. The recommended replacement ratios are between 20 and 40% and between 20 and 30% for Type I and Type II, respectively.

Fly ash reduces autogenous shrinkage and drying shrinkage of self-compacting concrete, but has certain effects on its early strength and setting time. Special care should be exercised when a large dosage of an air-entraining and high-range water-reducing admixture or superplasticizer is used as in the case of self-compacting concrete. However, there have been reports on its application to structures requiring no high strength, such as back-fill concrete, in which the fly ash replacement ratio reached 60%.

16.3 Production and execution

- (1) Self-compacting concrete shall be produced and executed under careful control according to a specially formulated plan.
- (2) When using fly ash for self-compacting concrete, special care shall be exercised in regard to curing of concrete.

[Commentary]

Regarding (1): Adequate planning and control are vital for self-compacting concrete in regard to its production, transportation, placing, finishing, curing, formwork, supports, etc, as its properties widely differ from those of normal concrete.

The mixing time of self-compacting concrete containing fly ash must be adequately established so that the materials can be uniformly blended, since such concrete has a high powder content compared with normal concrete.

Special attention should be paid to production control to produce concrete with a minimum scatter, as the qualities of this type of fresh concrete are vulnerable to fluctuations in the material qualities.

Meticulous care should be exercised for formulating a concrete placement plan, since the changes in the properties of concrete containing fly ash can vary depending on the qualities of fly ash. Adequate proportioning and selection of placing equipment are particularly important when such concrete is pumped, since its pumping resistance is higher than that of normal concrete, and its qualities can be altered after pumping.

Regarding (2): Having little bleeding water, self-compacting concrete is vulnerable to plastic cracking when the surfaces become dry after placing. Moist curing should be carried out according to an adequate curing plan, as it is important for concrete containing fly ash from the aspect of ensuring strength development and durability as well.

CHAPTER 17 CONCRETE PRODUCTS

17.1 Scope

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

[Commentary]

This chapter describes matters requiring special attention when using fly ash as a mineral admixture for concrete in plants where the production processes are consistently controlled. Concrete products include unreinforced and reinforced concrete products and prestressed concrete products. For matters regarding concrete products not specified in this chapter, the Standard Specification [Construction] should be observed.

17.2 General

When using fly ash for concrete products as a mineral admixture, particular care shall be exercised for the selection of the type and replacement ratio of fly ash, mixing, consolidation, and curing so that the effect of using fly ash can be fully developed.

[Commentary]

Since fly ash is capable of improving concrete properties while fresh owing to the geometry of its particles, it is used for concrete products to improve the placeability of concrete during production. Also, fly ash forms stable hardened paste by accelerated curing in an autoclave owing to its chemical composition (primarily SiO_2) with the strength development comparable to concrete with no fly ash. These characteristics depend on the type and replacement ratio of fly ash.

On the other hand, the qualities of fly ash depend on the type of coal and structure and type of boiler. It is therefore necessary to adequately select the type and replacement ratio of fly ash with due consideration to its qualities, in order to obtain concrete with the required qualities. Also, great care should be exercised when doing unaccelerated normal curing, as the strength development is retarded depending on the fly ash replacement ratio.

JIS A 6201 specifies four types of fly ash (Types I to IV). Type III has a higher ignition loss and Type IV has a lower fineness than Types I and II, and these are inferior in quality. Types III and IV may not produce the anticipated effect of improving the workability of concrete conventionally regarded as characteristic to fly ash. Accordingly, such fly ashes should be used with thorough grasp of their qualities.

17.3 Qualities of concrete

- (1) Concrete for concrete products shall have the required strength and durability with minimum variations in quality.
- (2) The standard strength of concrete for concrete products shall be the compression test value at 14 days.

[Commentary]

Regarding (1): Strength development of concrete containing fly ash generally tends to be retarded, and the degree of retardation primarily depends on the fineness and replacement ratio of fly ash. It is therefore necessary to thoroughly grasp the strength-developing property of concrete with the fly ash to be used to attain the required strength.

The durability of concrete containing fly ash may be regarded as similar to that of non-fly ash concrete, if fly ash having an effect of improving concrete fluidity (Type I or Type II) is used. However, when using fly ash with a high ignition loss (Type III) or low fineness (Type IV) with little prospect of improving the fluidity, consideration should be given to mix proportions, such as to maintain the water-binder ratio at a low level.

Regarding (2): When using Type IV fly ash, care should be exercised in proportioning and selection of the replacement ratio, as the reactivity of Type IV with cement is generally lower than other types. With such care being exercised, the control age of strength may be set at 14 days similarly to concrete with no fly ash.

For concrete products subject to special accelerated curing, such as autoclave curing, the strength develops at an early stage with little prospect of later strength gains. In such a case, test results at an age earlier than 14 days, such as 7 days, may be regarded as a standard for strength control.

17.4 Type and replacement ratio of fly ash

The type and replacement ratio of fly ash shall be adequately selected in consideration of the methods of molding and curing.

[Commentary]

According to JIS A 6201, Type I and Type II fly ashes are covered by conventional JIS specifications, whereas the ignition loss and fineness of Type III and Type IV, respectively, are outside the scope of conventional specifications. These types should therefore be used with due consideration to the properties of concrete containing them. Particular considerations are required for Type III and Type IV fly ashes in regard to air content and strength development after curing, respectively.

The type and replacement ratio of fly ash are summarized in Chapter 2 of the present Recommendations. Since Type III and Type II are similar in terms of contribution to strength development, Types I, II, and III can be used for concrete similarly to conventional practice. However, as Type III may not contribute to fluidity improvement, care should be exercised in proportioning not to increase the water-binder ratio from the aspect of durability.

Type IV fly ash is recommended for applications in which the strength is not predominantly important, such as unreinforced concrete products in general and fish banks, since its strength-developing property is inferior to other types.

When combining steam curing and autoclave curing for concrete containing Type II fly ash, a replacement ratio of 40% is effective in developing strength. Though similar hardening reaction during autoclave curing is anticipated for Types I, III, and IV as well, there has not been sufficient experience for these types. Preliminary examination should therefore be necessary for these types, such as to confirm the strength development by combinations of fly ash types and replacement ratios.

17.5 Accelerated curing

Accelerated curing of concrete containing fly ash shall not cause deleterious cracking in the concrete or adversely affect the long-term strength and durability of the concrete.

[Commentary]

Strength development of concrete containing fly ash depends on the combination of the type and replacement ratio

of fly ash and the accelerated curing conditions including the method and time of precuring and autoclave curing. It is therefore necessary to confirm the procedure that ensures the required strength and durability. The general practice comprises steam curing for 3 hours at 65°C as precuring followed by autoclave curing for 5 hours at 180°C under 11 atm.

17.6 Quality control and tests

- (1) The production of concrete products containing fly ash shall be controlled by establishing adequate criteria for materials, production procedure, and production equipment.
- (2) Strength tests on products and other necessary tests shall be conducted to judge the qualities of concrete products containing fly ash.

[Commentary]

Regarding (1): When producing concrete products containing fly ash, closer quality control than that for non-fly ash concrete products should be exercised throughout the production processes, including materials, production procedure, and equipment. This is because fluctuations of fly ash qualities, such as unburned carbon, fineness, and calcium content, strongly affect the chemical admixture demand, air content, and strength development of concrete. The use of fly ash with uniform qualities is particularly important when considering the production processes of fly ash. Particularly close control is required when using Type III and Type IV fly ashes, for which wide ranges of ignition loss and fineness are specified.

Regarding (2): The qualities of concrete products containing fly ash are affected by several factors in the processes from materials to curing. In order to maintain the required qualities of concrete products, it is important to thoroughly grasp the state of quality control of concrete containing fly ash. To this end, necessary tests must be duly conducted. One of the characteristics of concrete products is their direct applicability to strength testing to judge their quality. Concrete products must be tested by the method specified for each product type using actual products to confirm the attainment of the required qualities.

CHAPTER 18 OTHER SPECIAL CONCRETES

18.1 General

This chapter covers matters requiring special attention during concrete production and execution when using fly ash for concrete for uses other than normal and special uses covered by these Recommendations.

[Commentary]

Other special uses covered by this chapter refer to the use of fly ash for concrete to be used for applications other than normal uses (Chapters 2 to 8) and special uses (Chapters 9 to 17), namely, anti-washout underwater concrete, concrete for nonstructural members, grout, concrete with large fly ash content.

As for anti-washout underwater concrete, reference to the “Standard Specification for Design and Construction of Anti-washout Underwater Concrete Structures (Draft)” is recommended for matters not provided here.

18.2 Type and replacement ratio of fly ash

When using fly ash for other special concretes, the type and replacement ratio of fly ash shall as a rule be established by testing.

[Commentary]

(1) Anti-washout underwater concrete

Anti-washout underwater concrete is characterized by its large cement content and unit water content. For this reason, the fly ash content, when used, generally becomes higher than that for normal uses. This increases the effect of fly ash qualities on the concrete properties, particularly while fresh.

Fly ash is used for anti-washout underwater concrete to restrain the hydration heat generation resulting from the high cement content and improve the fluidity. However, the high fly ash replacement ratio can conversely affect

the setting of concrete by altering the adsorption of anti-washout underwater admixtures and air-entraining and water-reducing admixtures. This in turn affects the fluidity-retaining property of concrete. Also, the high unit water content requires considerations from the aspect of the durability of hardened concrete.

Though several study reports have been available on these points, conclusions are yet not to be drawn in regard to the above-mentioned subjects for each of the four fly ash types specified in JIS A 6201. Accordingly, the type and replacement ratio of fly ash are required as a rule to be established by testing trial mixtures of anti-washout underwater concrete with fly ash actually used for the project.

(2) Concrete for nonstructural members

Concrete for nonstructural members means concrete used in a condition that no load-bearing performance is required or concrete whose primary performance is not the load-bearing performance. In the present Recommendations, it generally refers to concrete with a compressive strength less than 18 N/mm^2 , the lower limit for reinforced concrete specified in the Standard Specification [Construction].

Though this type of concrete is basically used in a condition in which no high compressive strength is required (less than 18 N/mm^2), it is rational to set a target strength for proportioning before producing concrete.

Even in the case where no high strength is required, concrete is required to exhibit basic performance including minimum fluctuations in its qualities, a sufficient hardening rate to ensure the execution in line with the construction plan, and other necessary capabilities.

The use of fly ash for this type of concrete is intended to reduce the cement content from the aspect of conserving resources and improve the placeability of concrete, including fluidity. A technology of producing fish banks using ultra lean mixtures is a recent example.

Consequently, concrete for nonstructural members containing fly ash is required as a rule to be proportioned based on tests using materials including fly ash actually used in the project. However, if sufficient records are available and the qualities of concrete while fresh and when hardened are highly predictable, then the concrete may be proportioned referring to such records.

(3) Grout

Grout is a generic term for materials filled in spaces and gaps for the purpose of waterstopping, reinforcing, steel protection, and stabilization, and not necessarily concrete, but included in "concrete for other special uses."

Performances required of grout include high fluidity, minimum segregation, and small shrinkage. Fly ash is used for grout because it is a material suitable for grout to maintain these performances.

A wide variety of mix proportions are possible for grout, since it is used for various applications in the form of paste, mortar, or concrete. However, the above-mentioned basic performances are common to all forms. Though grout is scarcely applied to portions that assume major functions of a structure, it plays a supplementary role of making the structure function properly throughout its service life. It is therefore important to proportion grout to provide the required performance.

When using fly ash for grout, proportioning based on testing is required as a rule, since it is important that the grout is proportioned to fully develop the above-mentioned basic performances.

(4) Large-content application

Large-content application here refers to the three applications described below. There have naturally been little field experience and few study reports, because these are all relatively new and because Type III and Type IV fly ashes, which were out of standard in JIS A 6201-1996, are standardized in JIS A 6201-1999.

(a) A replacement ratio of over the upper limit, 30% (40% for Type I)

This type of application is mostly considered for dam concrete. Lean mixtures with a fly ash replacement ratio of over 40% are targeted. The idea of using large fly ash content for dam concrete is based on (1) proportioning to attain the required strength gains by maximizing the fly ash content without increasing the binder content or (2) proportioning to ensure the minimum cement content required for strength development while increasing the binder content, thereby increasing the replacement ratio.

(b) Large fly ash content as a mineral admixture in concrete having a binder content higher than normal concrete
This is a type of concrete that has a higher binder content than (a) and is premised on the use of an air-entraining and high-range water-reducing admixture or superplasticizer. It was developed in Canada with the aim of utilizing fly ash and is studied in Japan as well with field experience. The binder content is around 400 kg/m^3 , while the fly ash content exceeds 200 kg/m^3 . This type of concrete is highly placeable and exhibits improved hydration heat generation due to fly ash, providing significantly high strength depending on the mix proportions. The problem is the adsorption of the air-entraining and high-range water-reducing admixture or superplasticizer on fly ash particles. Generally speaking, fly ash with a higher fineness or higher ignition loss requires a higher dosage of an air-entraining and high-range water-reducing admixture or superplasticizer to satisfy the same proportioning requirements.

When applying fly ash to self-compacting concrete, which has an even higher binder content, reference to Chapter 16 of the present Recommendations and the Recommendations for Self-compacting Concrete is recommended.

(c) Use of fly ash as a mineral admixture supplementing fine aggregate

Whereas fly ash is generally used as a replacement for part of cement as a binder, this method retains the cement content unchanged to ensure strength development, while supplementing fine aggregate with fly ash. This in effect can be regarded as equivalent to a conventional method in which fly ash is added at a certain percentage of cement. Fly ash contributes to additional strength development and densification of the microstructure and produces a fluidity-improving effect.

From the aspect of supplementing fine aggregate, Type IV fly ash with coarse grains may be conceivable. However, the effects of fly ash qualities on the resulting fresh concrete properties are the same as in the case of using fly ash as a binder. It is therefore necessary to thoroughly grasp the relationship between fly ash qualities and resulting concrete to obtain concrete with the required performance.

Those described above are examples of large-content applications of fly ash. The attainment of the required qualities should be confirmed in each type of application by relevant test methods, as data and field experience are limited for the various types of fly ash covered by JIS A 6201.

JIS A 6201-1999
Fly Ash for Use in Concrete

1. Scope

This Japanese Industrial Standard specifies fly ash for use as a mineral admixture in concrete or mortar.

2. Reference standards

The following standards shall form a part of this standard by being referred to in this standard. The latest editions of these standards shall be applied.

- JIS H 6201 Platinum crucibles for chemical analysis
- JIS M 8819 Coal and coke—Mechanical methods for ultimate analysis
- JIS P 3801 Filter paper (for chemical analysis)
- JIS R 1301 Porcelain crucibles for chemical analysis
- JIS R 1603 Methods for chemical analysis of fine silicon nitride powders for fine ceramics
- JIS R 5201 Physical testing methods of cement
- JIS R 5210 Portland cement
- JIS Z 1505 Kraft paper sacks—for cement
- JIS Z 8401 Rules for rounding off of numerical values
- JIS Z 8801 Test sieves

3. Definitions

The definitions of certain terms used in this standard are as follows:

- a) Reference mortar: Mortar made using normal portland cement for use as a reference in quality testing of fly ash.
- b) Test mortar: Mortar for quality testing of fly ash made using normal portland cement and fly ash at 3:1 by mass.
- c) Flow value ratio: The percent ratio of the flow value of test mortar to the flow value of reference mortar.
- d) Activity index: The percent ratio of the compressive strength of test mortar to the compressive strength of reference mortar.

4. Classification

Fly ash for use in concrete shall be classified into the following four types:

- a) Type I
- b) Type II
- c) Type III
- d) Type IV

Table 1 Qualities of fly ash

Fly ash type		Type I	Type II	Type III	Type IV
Silicon dioxide (%)		≥45.0			
Moisture content (%)		≤1.0			
Ignition loss ¹⁾ (%)		≤3.0	≤5.0	≤8.0	≤5.0
Density (g/cm ³)		≥1.95			
Fineness ²⁾	Part retained on a 45μm sieve (mesh sieve method ³⁾ , %)	≤10	≤40	≤40	≤70
	Specific surface area (Blaine method, cm ² /g)	≥5,000	≥2,500	≥2,500	≥1,500
Flow value ratio (%)		≥105	≥95	≥85	≥75
Activity index	28 days	≥90	≥80	≥80	≥60
	91 days	≥100	≥90	≥90	≥70

Notes: 1) The ignition loss values specified for the unburned carbon content measured in accordance with JIS M 8819 or JIS R 1603 may be adopted instead of the ignition loss measurements.

2) The fineness shall be measured by the mesh sieve method or the Blaine method.

3) When measuring the fineness by the mesh sieve method, the specific surface test results by the Blaine method shall be indicated as a reference.

5. Qualities

The qualities of fly ash shall conform to the requirements of Table 1 by testing in accordance with Section 8.

6. Uniformity of qualities

The uniformity of qualities in terms of fineness shall be as follows:

- a) When evaluating the fineness of fly ash by the mesh sieve method, the part retained on a 45 µm sieve shall not differ by more than 5% from the value for the submitted sample⁴⁾.
- b) When evaluating the fineness of fly ash by the Blaine method, the specific surface area shall not differ by more than 450 cm²/g from the value of the submitted sample⁴⁾.

Note: 4) The value for the submitted sample is the standard value agreed on between the parties concerned.

7. Samples

7.1 Sampling

The quantity and method of sampling shall be as agreed between the parties concerned.

7.2 Preparation

Samples shall be prepared in accordance with Section 4. (2) of JIS R 5201.

8. Test methods

8.1 Silicon dioxide

Silicon dioxide samples shall be taken as follows:

- a) Accurately weigh a sample of approximately 0.5 mg to the nearest 0.1 mg and place in a crucible specified in JIS H 6201 (PTCR 20, PTCR 25, and PTCR 30) (m_1).
- b) Add 3 to 5 g of a mixed flux [1 part sodium carbonate (anhydride) + 1 part potassium carbonate (by mass)] and uniformly mix with the sample. Cover the mixture with a small amount of the mixed flux.
- c) Lid the crucible and slowly heat it. Ignite further for 20 to 30 minutes after the contents have melted.
- d) Leave the crucible to cool. Separate the fusion from the crucible and transfer to a porcelain evaporating dish (120 mm). Wash the crucible and lid with a small amount of hydrochloric acid (1+1) and warm water, and add the washings to the porcelain evaporating dish.
- e) Cover the porcelain evaporating dish with a watch glass, gently add 15 to 20 ml of hydrochloric acid little by little to dissolve the fusion, and then evaporate the solution to dryness in the evaporating dish on a water bath. During the evaporation to dryness, break dry contents and blend occasionally with a glass rod to prevent forming of large lumps. Make sure that the contents are completely evaporated to dryness.
- f) After leaving the sample to cool, add approximately 10 ml of hydrochloric acid, mix, and leave to stand for 1 to 2 minutes. Add water to approximately 100 ml and dissolve soluble chlorides by heating the mixture for approximately 5 minutes on the water bath.
- g) Filtrate the solution through filter paper specified in JIS P 3801 (Type 5 B 110 mm) and wash with warm water until chloride ions are scarcely recognized in the washings.

Note: 5) Ten to twelve times of washing are sufficient.

- h) Transfer the filtrate and washings to a porcelain evaporating dish, evaporate to dryness again on the water bath, and finally heat the dry filtrate at 110 to 115°C for 1 hour in an air bath. Then filtrate again by the same operation.
- i) Place the deposit obtained in g) and h) in a crucible and dry. Heat slowly and ash the filter paper, taking care to avoid flaming. Then ignite the residue in an electric furnace with the temperature adjusted to 1000 ± 50°C for 1 hour. Leave the residue to cool in a desiccator and measure the mass (m_2).
- j) Calculate the silicon dioxide content by the following equation and round off in accordance with JIS Z 8401 to one decimal place:

$$A = \frac{m_2}{m_1} \times 100$$

where A = silicon dioxide content (%)

m_1 = mass of sample (g)

m_2 = mass of deposit (g)

8.2 Moisture content

Testing for the moisture content shall be conducted as follows:

- a) Accurately weigh approximately 2 g of sample to the nearest 0.1 mg (m_3) and place in a flat weighing bottle (50 mm). Spread the sample thinly and dry without the lid in an air bath adjusted to a temperature of 105 to 110°C for 2 hours. Lid the weighing bottle, leave to cool in a desiccator, and measure the mass.

- b) Repeat 1-hour drying processes to constant weight⁶⁾ and determine the loss (m_4).

Note: 6) When the difference between the mass before and after drying becomes 0.5 mg or less.

- c) Calculate the moisture content by the following equation and round off to one decimal place in accordance with JIS Z 8401.

$$B = \frac{m_4}{m_3} \times 100$$

where B = moisture content (%)
 m_3 = mass of sample (g)
 m_4 = loss when a constant weight is reached (g)

8.3 Ignition loss

Ignition loss testing shall be conducted as follows:

- a) Accurately weigh approximately 1 g of sample to the nearest 0.1 mg (m_5) and place in a crucible specified in JIS R 1301 (capacity: 15 ml) and ignite in an electric furnace adjusted to a temperature of $975 \pm 25^\circ\text{C}$ for 15 minutes. Leave the residue to cool in a desiccator and measure the mass.
b) Repeat 15-minute drying processes until constant weight⁷⁾. Calculate the ignition loss from the loss when a constant weight is reached (m_6) and round off to one decimal place in accordance with JIS Z 8401:

$$C = \frac{m_6}{m_5} \times 100 - B$$

where C = ignition loss (%)
 m_5 = mass of sample (g)
 m_6 = loss when a constant weight is reached (g)

Note: 7) When the difference between the mass before and after ignition becomes 0.5 mg or less.

8.4 Density

Testing for density shall be conducted following the requirements of Section 6 (Density test) of JIS R 5201⁸⁾. However, the mass of sample shall be 70 g.

Note: 8) Care shall be exercised to thoroughly deaerate the sample, as deaeration is more difficult than in the case of cement.

8.5 Fineness

8.5.1 Part retained on a 45- μm sieve (mesh sieve method)

Testing for part retained on a 45- μm sieve shall be conducted in accordance with Appendix 1.

8.5.2 Specific surface area (Blaine method)

Testing for specific surface area shall be conducted following the requirements of Section 7.1 of JIS R 5201. However, the mass of sample shall be weighed so that the porosity of the sample can be as close to the porosity of the standard sample and the compressed specimen can be packed under a pressure similar to that for cement.

8.6 Flow value ratio

Testing for flow value ratio shall be conducted in accordance with Appendix 2.

8.7 Activity index

Testing for activity index shall be conducted in accordance with Appendix 2.

9. Inspection

Inspection of fly ash shall be carried out by taking samples by a rational sampling method and testing as specified in Section 8. Fly ashes conforming to Sections 5 and 6 shall be accepted.

10. Packaging

When packaging fly ash, sacks following cement kraft paper sacks specified in JIS Z 1505 shall be used.

11. Marking

The following marks shall be indicated on the paper sack if fly ash is packaged, or on the invoice if not packaged. The shipping date may be indicated in an adequate form by agreement between the parties concerned.

- Name of product (type of fly ash)
- Net mass
- Name of manufacturer

12. Report

The manufacturer shall submit the certificate of analysis at the request of the purchaser. The form of a certificate of analysis shall in principle be as shown in Table 2.

Table 2 Form for certificate of analysis

Certificate of Analysis for Fly Ash						
Year: _____ Month: _____		Manufacturer: _____				
Type		JIS A 6201 specifications (Circle the relevant type)				Test value
Quality		Type I	Type II	Type III	Type IV	
Silicon dioxide (%)		≥45.0	≥45.0	≥45.0	≥45.0	
Moisture content (%)		≤1.0	≤1.0	≤1.0	≤1.0	
Ignition loss ¹⁾ (%)		≤3.0	≤5.0	≤8.0	≤5.0	
Density (g/cm ³)		≥1.95	≥1.95	≥1.95	≥1.95	
Fine-ness ²⁾	Part retained on a 45-μm sieve (mesh sieve method ³⁾ , %)	≤10	≤40	≤40	≤70	
	Specific surface area (Blaine method, cm ² /g)	≥5,000	≥2,500	≥2,500	≥1,500	
Flow value ratio (%)		≥105	≥95	≥85	≥75	
Activity index	28 days	≥90	≥80	≥80	≥60	
	91 days	≥100	≥90	≥90	≥70	
Notes: 1) When the measurements of the unburned carbon content were used, “(carbon)” shall be indicated with the test value. 2) The fineness shall be measured by the mesh sieve method or the Blaine method. 3) When measuring the fineness by the mesh sieve method, the specific surface test results by the Blaine method shall be indicated as a reference.						
Contact: (Company name, Section in charge) (Address) (Phone)						

Remark: The paper size for the form shall be A4 specified by JIS (210×297 mm).

Appendix 1 (Normative)

Test Method for Part Retained on a 45-μm Sieve (Mesh Sieve Method)

1. Scope

This appendix specifies the test method for part retained on a 45-μm sieve as one of the fineness test methods of fly ash.

2. Apparatus

2.1 Test sieve

The test sieve shall be a 45-μm mesh sieve specified in JIS Z 8801 having a frame 50 mm in internal diameter and 75 mm in depth.

2.2 Spray nozzle

A spray nozzle having 17 orifices 0.5 mm in diameter at its end and a pressure gage to confirm the water pressure shall be used.

2.3 Precision balance

A precision balance readable and accurate to 0.1 mg shall be used.

3. Materials for testing

3.1 Water for testing

Water for testing shall be distilled water or tap water.

3.2 Standard samples for calibration

Standard cement samples for fineness measurement shall be used as the standard samples for calibration.

4. Test procedure

The test procedure shall be as follows:

- Accurately weigh the mass of only the sieve.
- Accurately weigh 1 g of sample to the nearest 0.1 mg and place in the sieve.
- When the sample powder in the sieve agglomerates, break the agglomerates by lightly pressing them onto the

sieve frame with, for example, the tip of a paint brush, before washing with water.

- d) After wetting the sample with a gentle water flow, wash the sample for 1 minute by applying water to the sample using a spray nozzle at a water pressure of 0.069 ± 0.005 MPa while moving the sieve in a circular motion at a rate of one cycle per second.
- e) Thoroughly remove water drops remaining under the sieve with soft paper.
- f) Place the residue together with the sieve in a dryer maintained at 100 to 110°C beforehand, dry for 15 minutes, and allow to cool in a desiccator. Accurately weigh the mass of the sieve with the residue to the nearest 0.1 mg, and determine the mass of the residue by subtracting the mass of the sieve alone before testing.

5. Calculation of part retained on a 45-μm sieve

5.1 Part retained on a 45-μm sieve

The part retained on a 45-μm sieve shall be calculated by the following equation and rounded off to an integer in accordance with JIS Z 8401:

$$f = \frac{m_2}{m_1} \times C \times 100$$

where
f = part retained on a 45-μm sieve (%)
m₁ = initial mass of sample (g)
m₂ = mass of residue (g)
C = calibration factor of mesh sieve

5.2 Calibration of mesh sieve

For calibration of a mesh sieve, standard cement samples for fineness measurement shall be used. Part of the standard sample retained on the 45-μm sieve shall be measured in accordance with the method specified in Section 4, and the calibration factor of the mesh sieve shall be determined by the following equation:

$$C = \frac{\gamma_0}{\gamma}$$

where
C = calibration factor of mesh sieve
γ₀ = standard value of part retained on a 45-μm sieve of standard sample
γ = measured value of part retained on a 45-μm sieve of standard sample

Appendix 2 (Normative)

Test Method for Flow value ratio and Activity Index of Fly Ash in Mortar

1. Scope

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

2. Apparatus

The apparatus shall be as specified in Sections 8.1 (2) (Mechanical mixer), (3) (Mixing apparatus for hand mixing), 10.1 (2) (Molds for mortar specimens), (3) (Molder), (4) (Compression testing machine), (5) (Flexure testing machine), and 11.1 (1) (Flow table, flow cone, and tamping rod) of JIS R 5201.

Weighing shall be carried out using a balance readable to 10 mg.

3. Materials for testing

3.1 Cement

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

3.2 Standard sand

The standard sand shall be as specified in Section 10.2 of JIS R 5201.

3.3 Water

Water shall be distilled water or tap water.

4. Samples

An adequate amount of sample shall be taken in accordance with Section 7.1 of the present JIS, reduced, and stored in moisture-proof airtight containers. An adequate amount here refers to an amount that will make a sample of 5 kg or more after reduction.

5. Temperature and relative humidity

The temperature and relative humidity of the laboratory where the specimens are molded shall be $20 \pm 2^\circ\text{C}$ and 50% or more, respectively. The temperature and relative humidity of the moist closet to store molded specimens shall be $20 \pm 1^\circ\text{C}$ and 90% or more, respectively. The water temperature of the water tank shall be $20 \pm 1^\circ\text{C}$.

6. Test methods

6.1 Mix proportions of mortar

Mortar shall be proportioned as specified in Appendix 2 Table 1.

Appendix 2 Table 1 Mix proportions of mortar (in g)

Type of mortar	Cement	Sample	Standard sand	Water
Reference mortar	450 ± 2	0	$1,350 \pm 5$	225 ± 1
Test mortar	337.5 ± 1.5	112.5 ± 0.5		

Remark: Appendix 2 Table 1 indicates the amount of one batch, which will provide mortar sufficient for three specimens or two flow tests.

6.2 Mixing

Mortar shall be mechanically mixed using a mixer specified in Section 8.1 (2) of JIS R 5201 as follows: Set the mixing bowl and paddle. Charge the mixing bowl with the specified amount of water. Add cement in the case of reference mortar, or cement and sample in the case of test mortar. Immediately activate the mixer at a low speed (rotation speed: 140 ± 5 cycles per minute, revolution speed: 62 ± 5 cycles per minute). Thirty seconds after activating the paddle, add the specified amount of standard sand within the next 30 seconds. Switch to the high speed (rotation speed: 285 ± 10 cycles, revolution speed: 125 ± 10 cycles) and continue mixing for another 30 seconds. Stop mixing for 90 seconds. During the first 30 seconds of this rest period, scrape the adhering mortar off the wall of the mixing bowl. Mix again at a high speed for 60 seconds. The overall mixing time including the rest period is 4 minutes.

After mixing, dismount the mixing bowl from the mixer and remix with a spoon¹⁾ for 10 strokes.

Note: 1) A spoon specified in Section 8.1 (3) of JIS R 5201 shall be used.

6.3 Flow test

A flow table, flow cone, and tamping rod specified in Section 11.1 (1) of JIS R 5201 shall be used for flow testing.

Fill the mortar in two layers in a flow cone placed properly in the center of a flow table thoroughly wiped with a dry cloth. Rod each layer with a tamping rod in 15 strokes to half the depth of the layer, distributing the strokes uniformly over the cross section of the cone. Add mortar to overfill the cone and strike off. Immediately raise the cone properly and apply 15 dropping motions in 15 seconds. Measure the diameters of the spread mortar in the direction where it is recognized as the largest and in the direction perpendicular to it, and express their average in an absolute integer in mm. Conduct two tests and take the average as the flow value.

Mortar used for flow tests shall not be used for compression tests.

6.4 Compression test

6.4.1 Fabrication of specimens

Specimens shall be fabricated as follows:

- Size—Specimens for compression testing shall be beams 160 mm in length having a square cross section 40 by 40 mm in size. Molds shall as a rule conform to Section 10.1 (2) of JIS R 5201.
- Molding—Specimens shall be fabricated immediately after mortar mixing. Employ a vibrating table specified in Section 10.1 (3) of JIS R 5201 as the molder. Mount the supporting frame and fix the molds for mortar specimens on the vibrating table. The overall vibration time of a vibrating table shall be 120 ± 1 seconds. Mortar shall be filled in molds in two layers.

Mortar for the first layer shall be filled up to 1/2 the depth of the mold in 15 seconds from the beginning of vibration using a spoon. Stop the filling operation during the next 15 seconds. Fill the rest of the mortar during the next 15 seconds in the same order as the first layer while gathering mortar in the bowl with the spoon. Apply the vibration further for 75 seconds.

When the vibration has ended, gently dismount the molds from the vibrating table and remove the supporting frame. Overfill the molds to approximately 5 mm with the remaining mortar and place in a moisture closet. When the bleeding has subsided²⁾, strike off the excess mortar and smooth the top surface.

Striking off shall be carried out using a metal straightedge (see Reference Fig. 1). Hold the straightedge upright and move along the top edge of the mold once each in the longitudinal and transverse directions while moving it in sawing motions. Finally, smooth the top surface by moving the straightedge slanted towards the direction in which it proceeds in one light stroke without pressing the mortar.

After striking off, place a glass plate 190 mm by 160 mm in size and 6 mm in thickness on the mold. Steel or

other impermeable plates of a similar size may be used.

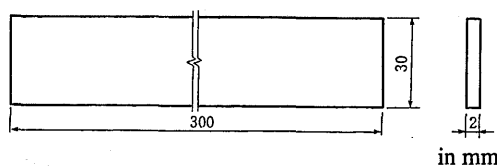
Mark the mold for identification at the time of demolding and place in a moisture closet. For testing at an age later than 1 day, mark the specimens and carefully demold them between 20 and 24 hours after placing. Place the specimens in a water tank, completely immersing in water. For testing at an age of 1 day, demold the specimens 20 minutes before testing and cover them with a wet cloth until testing.

When changing the curing water, total replacement all at once shall be avoided.

Note: 2) The standard time for subsidence of bleeding shall be 3 hours.

Remark: 1. Molds shall be greased before fastening to prevent leakage.

2. Cement, standard sand, and water shall be prepared in the laboratory to equalize their temperatures with the room temperature.



Reference Fig. 1 Metal straightedge (approximate size)

6.4.2 Measurement

Machinery specified in Section 10.1 (4) of JIS R 5201 shall be used for the compression testing. The testing ages shall be 28 days (24 hours in a moisture closet and 27 days in water) and 91 days (24 hours in a moisture closet and 90 days in water).

Compression testing shall be conducted as follows: prepare six specimens by cutting three specimens into two at the above-mentioned ages using a machine specified in Section 10.1 (5) of JIS R 5201. Turn each specimen on its side with respect to its position as molded and apply loading to the center across a loading plate at a rate of $2,400 \pm 200$ N per second to determine the maximum load.

7. Calculation of flow value ratio and activity index

7.1 Flow value ratio

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

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

where F = flow value ratio (%)
 l_1 = flow value of reference mortar
 l_2 = flow value of test mortar

7.2 Activity index

The activity index shall be calculated by the following equation and rounded off to an integer in accordance with JIS Z 8401:

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

where A = activity index (%)
 c_1 = average compressive strength of six reference mortar specimens at each test age (N/mm^2)
 c_2 = average compressive strength of six test mortar specimens at each test age (N/mm^2)

JSCE Standard JSCE-D107-1999
Standard Specification for Air-Entraining Admixtures for Fly Ash (Draft)

1. Scope

This standard specification covers the qualities of air-entraining admixtures for fly ash to be used in the production of concrete containing fly ash as a mineral admixture when the required air content cannot be constantly obtained by the use of other chemical admixtures available on the market.

2. Definitions

The definitions of certain terms of this specification shall be in accordance with JIS A 0203 (Concrete terminology) and as follows:

Air-entraining admixture for fly ash: an air-entraining admixture for concrete containing fly ash, which minimizes the changes in air content over time after mixing.

3. Qualities

Air-entraining admixtures for fly ash shall exhibit qualities conforming to the performance requirements for air-entraining admixtures specified in JIS A 6204 (Chemical admixtures for concrete) and also shall be capable of limiting the change in air content of concrete at 60 minutes after mixing to a range between +0.5% and -1.5% measured by testing in accordance with Section 4.

4. Test method

4.1 Materials for testing

- (1) Materials for testing other than fly ash shall conform to Section 5.1.1 of JIS A 6204.
- (2) The fly ash shall be Type II¹⁾ conforming to JIS A 6201 and shall meet the fly ash content requirement in Section 4.2 with a replacement ratio of 50% or less.

Note: 1) The fly ash shall have an ignition loss of 3 to 5% and a methylene blue adsorption of 0.5 to 0.9 mg/g or a specific surface area by the BET method of 2 to 4 m²/g.

4.2 Proportioning

(1) Binder content

The binder content shall be 320 kg/m³.

(2) Fly ash content

The fly ash content shall be selected so that the ignition loss of fly ash contained in 1 m³ of concrete would be 4.8 kg.

(3) Unit water content

The unit water content shall be determined to provide an as-mixed slump of 18 ± 1 cm.

(4) Dosage of air-entraining admixture for fly ash

The dosage of air-entraining admixture for fly ash per m³ of concrete shall be determined based on trial mixtures referring to the dosage specified by the manufacturer.

(5) Air content

The as-mixed air content of concrete shall be 4.5 ± 0.5%.

(6) Sand-aggregate ratio

The sand-aggregate ratio shall be established within the range of providing high workability.

4.3 Method of producing concrete

The method of producing concrete shall be in accordance with JIS A 1138 (Method of making test samples of concrete in the laboratory).

4.4 Concrete test

(1) Slump

Slump testing shall be conducted in accordance with JIS A 1101 (Method of test for slump of concrete).

(2) Air content

Air content testing shall be conducted in accordance with JIS A 1128 (Method of test for air content of fresh concrete by pressure method) or JIS A 1116 (Method of test for unit mass and air content mass type of fresh concrete).

(3) Changes in air content over time

Testing for air content changes over time shall be conducted in accordance with (a) through (d) below.

- (a) Discharge concrete mixed in accordance with Section 4.3 onto a mixing pan, remix it, and immediately measure the slump and air content twice each.
- (b) Retain the remaining concrete on the mixing pan and maintain it in a condition causing no loss or gain of

water by covering it with vinyl sheeting.

- (c) Sixty minutes after the beginning of mixing, uncover the concrete, remix it, and measure the air content twice.
- (d) The air content immediately after mixing and at 60 minutes after mixing shall be the averages of the two respective measurements.

4.5 Air content change over time

The air content change over time shall be calculated by the following equation using the air content determined in Section 4.4.

$$\text{Air content change over time (\%)} = A_{60} - A_0$$

where A_{60} = air content 60 minutes after mixing (%)

A_0 = air content immediately after mixing (%)

5. Inspection

Air-entraining admixtures for fly ash shall be inspected by sampling by a rational sampling method and testing in accordance with Section 4. Those conforming to the requirements of Section 3 shall be accepted.

JSCE Standard JSCE-D503-1999
Test Method for Replacement Ratio of Fly Ash Used as a Mineral Admixture (Draft)

1. Scope

This standard covers tests for estimating the replacement ratio of fly ash used as a mineral admixture in fresh concrete.

2. Apparatus and reagents

2.1 Apparatus and reagents for sampling and preparation

The apparatus and reagents for sampling and preparation described in Section 3 shall be as follows, in addition to those specified in JIS A 1115 (Method of sampling fresh concrete) and JIS A 1112 (Method of test for washing analysis of fresh concrete):

- (1) The apparatus for suction filtration shall be as illustrated in Figs. 1 and 2.
- (2) Beakers (100 ml) shall be as specified in JIS R 3503 (Glass apparatus for chemical analysis).
- (3) Glass-fiber filter paper shall be of a pore size of approximately 1 μm .
- (4) Acetone shall conform to JIS K 8034 (Acetone (Reagent)).

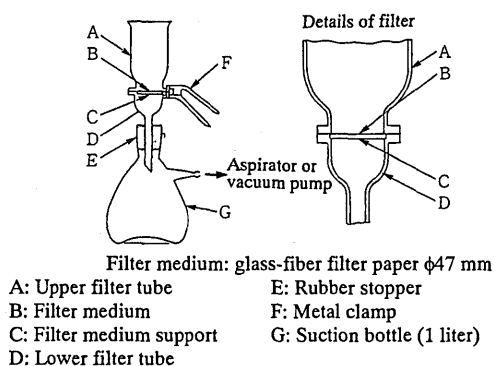


Fig. 1 Example of suction filtration apparatus

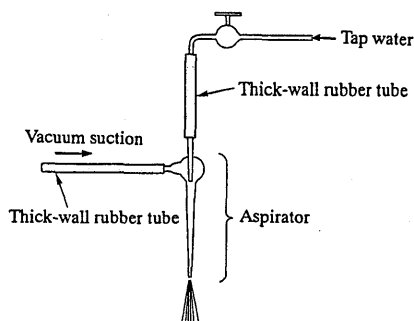


Fig. 2 Example of aspirator (Water jet pump)

2.2 Apparatus and reagents for analysis

The apparatus and reagents used for the analysis method described in Section 4 shall be as follows:

- (1) The chemical balance shall have a weighing capacity of around 100 g and a reciprocal sensibility of 0.1 mg.
- (2) The magnetic stirrer and other stirrers shall be capable of thoroughly stirring a solution of 500 ml.
- (3) The electric furnace shall be capable of maintaining a temperature of 750°C for a long time.
- (4) Crucibles shall be either platinum crucibles (No. 30) specified in JIS H 6201 (Platinum crucibles for chemical analysis) or porcelain crucibles (Type B, 30 ml) specified in JIS R 1301 (Ceramic crucibles for chemical analysis).
- (5) Hydrochloric acid (1+100) shall conform to JIS K 8180 (Hydrochloric acid (Reagent)).

3. Sampling and preparation

3.1 Sampling of concrete

A concrete sample shall be taken in accordance with JIS A 1115 to obtain a representative sample of approximately 30 liters.

When sampling from an agitating truck, samples may be obtained from the middle portion of the batch discharge, avoiding the very first and last portions.

3.2 Sample extraction

- (1) Remix the concrete sample immediately on a mixing pan using a scoop. Sift the concrete through a 5-mm sieve to separate a mortar sample of approximately 500 (or 50) g.
- (2) Sift the mortar sample using a 0.6-mm sieve and then a 0.075-mm sieve while washing with water¹⁾, and gather particles finer than 0.075 mm in a container together with the washings.

Note: 1) Washing may be carried out using a dropper.

- (3) Leave the suspension to stand for approximately 5 minutes to precipitate fine particles. Remove the supernatant gently to avoid re-suspension²⁾. Thoroughly agitate the concentrated suspension in the bottom using a glass rod.

Note: 2) A small battery-powered hand-held pump is recommended.

3.3 Hydration termination and drying

- (1) Suction-filtrate the suspension obtained in Section 3.2 (3) through glass-fiber filter paper.
- (2) Transfer part of the sample obtained in Section 3.3 (1) to a beaker (100 ml) so that a dry sample of approximately 5 g can be obtained. Add acetone approximately 5 times the sample by volume and agitate thoroughly to remove water. Suction-filtrate the suspension. Repeat the process three times to dehydrate the sample and secure termination of hydration.
- (3) Dry the sample at a temperature of $105 \pm 5^{\circ}\text{C}$ to constant weight³⁾ and place in an airtight container. Leave it to cool and store.

Note: 3) A drying period of 3 hours is normally sufficient.

Remark: 1. When stored in an airtight container, samples can be used for analysis after storage for several months.

4. Analysis procedure

- (1) Transfer the sample to an agate mortar, lightly mix it with a pestle, and accurately weigh out approximately 1 g to the nearest 0.1 mg.
- (2) Charge a beaker with 500 ml of hydrochloric acid (1+100).
- (3) Add the weighed sample and 0.1 to 0.2 g of sodium pyrosulfite to the beaker and agitate for 20 minutes with a magnetic stirrer to dissolve the sample. Break large lumps with the tip of a glass rod.
- (4) After leaving the solution to stand for a few minutes, filtrate it through filter paper (Type 5 B, 11.0 cm) with filter powder, and rinse 10 times with warm water.
- (5) Place the residue in a crucible and dry. Heat slowly to ash the filter paper. Then ignite the residue in an electric furnace adjusted to $750^{\circ} \pm 50^{\circ}\text{C}$ for an hour.
- (6) Leave the residue to cool in a desiccator and measure the mass accurately to the nearest 0.1 mg.
- (7) Calculate the insoluble residue in the analysis sample by the following equation and round off to one decimal place in accordance with JIS Z 8401 (Rules for rounding off of numerical values)⁴⁾.

Note: 4) Carry out the analysis twice and take the average. The difference between the two measurements shall not exceed 2.0%.

$$I_b = \frac{m'}{m} \times 100$$

where I_b = insoluble residue of analysis sample (%)

m = mass of sample (g)

m' = mass of residue (g)

5. Calculation of replacement ratio of fly ash

The replacement ratio of fly ash in the binder shall be calculated by the following procedure and rounded off to an integer in accordance with JIS Z 8401 (Rules for rounding off of numerical values).

5.1 Calculation of powder fine aggregate content in concrete

The powder fine aggregate content in concrete, SL , shall be calculated by the following equation:

$$SL = S \times \frac{L_0}{100}$$

where SL = powder fine aggregate content (kg/m^3)

S = fine aggregate content given in the field mix table⁵⁾ (kg/m^3)

L_0 = percentage passing a 75- μm sieve (%)

Note: 5) Since the percentage passing a 75- μm sieve is based on the absolutely dry condition, it may be calculated from the fine aggregate content in the absolutely dry condition determined by correcting with the water absorption.

Remark: 2. In this test method, the replacement ratio shall be calculated on the assumption that the total cement and fly ash pass a 0.075 mm sieve. Therefore, the proportions of cement, fly ash, and fine aggregate powder in the analysis sample are assumed to be the same as the mass proportions of the cement content, fly ash content, and fine aggregate powder content of the concrete.

5.2 Calculation of cement and powder fine aggregate proportions in analysis sample

The ratios of cement (C_p) and fine aggregate powder (SL_p) in the analysis sample shall be calculated by the following equations:

$$C_P = \frac{C}{C + F + SL}$$

$$SL_P = \frac{SL}{C + F + SL}$$

where C_P = proportion of cement in the analysis sample
 SL_P = proportion of powder fine aggregate in the analysis sample
 C = cement content given in the field mix table⁶⁾ (kg/m³)
 F = fly ash content given in the field mix table⁶⁾ (kg/m³)
 SL = powder fine aggregate content determined in Section 5.1 (kg/m³)

Note: 6) The accuracy of estimation for the fly ash replacement ratio is increased by measuring beforehand the amount passing a 0.075-mm sieve of the actually used cement and fly ash and then correcting the contents.

5.3 Calculation of fly ash replacement ratio

(1) Proportion of fly ash in the analysis sample

The proportion of fly ash in the analysis sample shall be determined by the equation below using the insoluble residues of cement, fly ash, and fine aggregate powder, I_C , I_F , and I_{SL} , respectively, determined in Section 4.

$$F_P = \frac{I_b - C_P \times I_C - SL_P \times I_{SL}}{I_F}$$

Remark: 3. This equation is a rearrangement of the equation $C_P \times I_C + F_P \times I_F + SL_P \times I_{SL} = I_b$.

(2) Replacement ratio of fly ash

The replacement ratio of fly ash, R , shall be determined by the following equation using C_P determined in Section 5.2 and F_P determined in Section 5.3 (1):

$$R = \frac{F_P}{C_P + F_P} \times 100 = \frac{F_P}{1 - SL_P} \times 100$$

$$= \frac{I_b - C_P \times I_C - SL_P \times I_{SL}}{I_F (1 - SL_P)} \times 100$$

If the insoluble residues of the cement, fly ash, and powder fine aggregate used are not measured, then calculation shall be made by assuming them to be as follows:

$$I_C = 0.0^{7)} (\%)$$

$$I_F = 90.0^{8)} (\%)$$

$$I_{SL} = 100.0^{9)} (\%)$$

Note: 7) The insoluble residue of portland cement is normally in the range of 0.2 to 0.6% by this method and 0.4% on average. This is therefore negligible.

8) The insoluble residue of fly ash is normally in the range of 85 to 95% by this method and 90% on average. This value was adopted as an assumption.

9) Though aggregate partially dissolves in dilute hydrochloric acid, the amount is negligible.

6. Report

The report shall include the required items of the following:

- (1) Type and source of fly ash
- (2) Type of cement
- (3) Type, origin, and fines content of aggregate
- (4) Mixture proportions and field mixture proportions of concrete
- (5) Portions from which samples are taken, date of sampling, time from the end of mixing to sampling, and concrete temperature
- (6) Time required from the end of mixing to the termination of hydration by acetone
- (7) Determined or assumed values of I_C , I_F , and I_{SL} , etc., used for the calculation
- (8) Place of analysis