Technical Report

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# Production and Use of Blast Furnace Slag Aggregate for Concrete

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## Abstract

***It has been more than 30 years since the use of blast furnace slag as concrete aggregate was included in JIS; however, it is not very popular today, and the annual sale of slag for aggregate use of Nippon Steel & Sumitomo Metal Corporation stays at the level of one million tons. With the latest trend toward a recycling oriented society, however, effective use of slag is attracting attention, and in view of this, the Company has studied the use of blast furnace slag as concrete aggregate for wider varieties of applications. The present paper reports an example where the slag was trial used as the concrete aggregate for road paving, as well as the quality control during the work and follow-up inspection of the pavement performance. The measures to solve the problems in the use of fine slag aggregate for concrete and its applicability to cast concrete products are also described herein.***

## 1. Introduction

Slag forms when iron ore is melted and reduced into molten pig iron in blast furnaces. The amount of slag generation is roughly 300 kg per ton of pig iron produced, and the annual production of blast furnace slag (BF slag) in Japan exceeds 24 million t (all units herein are metric).[1] As seen in **Fig. 1**, BF slag is divided into air-cooled slag and granulated slag. The former is produced by letting molten slag cool in open pits or yards, and the latter by rapidly cooling molten slag with water jet; the former looks like crushed stone and the latter like sand. Coarse aggregate of BF slag for concrete mixing is produced by crushing air-cooled slag and then classifying through screens; fine aggregate is produced by lightly crushing granulated slag to control the grain size and then classifying.

The technical development in Japan regarding BF slag aggregate (coarse and fine) for concrete began in the 1970s, and coarse slag aggregate was included in the JIS system as JIS A 5011 "Air Cooled Iron Blast Furnace Slag Aggregate for Concrete" in 1977 and fine BF slag aggregate as JIS A 5012 "Water Granulated Iron Blast Furnace Slag Aggregate for Concrete" in 1981. Thereafter, the two were unified as JIS A 5011-1 "Slag Aggregate for Concrete, Part 1 Blast Furnace Slag Aggregate". Then, in 1983, the Japan Society of Civil Engineers (JSCE) and the Architectural Institute of Japan (AIJ) instituted technical standards for structural design and casting work of concrete using BF slag as aggregate. Thereafter, the aggregate use of BF slag expanded, and in 2013, the use of fine BF slag aggregate for high-strength concrete up to 60 N/mm$^2$ was included in the "Recommendation for Practice of Concrete Making Use of Ground Granulated Blast Furnace Slag" published by the AIJ (see **Table 1**).

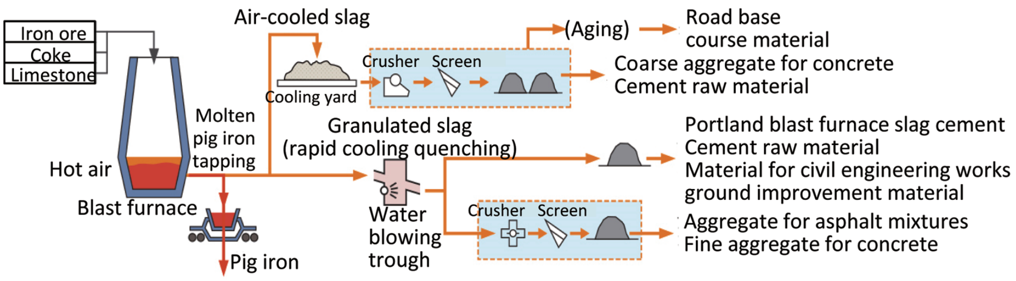


**Fig. 1 Production flow of the blast furnace slag**

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**Table 1 Standardization of BF slag use for concrete**

| | |
|---|---|
| 1977 | JIS A 5011 Air Cooled Iron Blast Furnace Slag Aggregate for Concrete |
| 1981 | JIS A 5012 Water Granulated Iron Blast Furnace Slag Aggregate for Concrete |
| 1983 | Japan Society of Civil Engineers and Architectural Institute of Japan, Practice of Concrete with Blast Furnace Slag Fine Aggregate |
| 1997 | JIS A 5011-1 Slag Aggregate for Concrete, Part 1: Blast Furnace Slag Aggregate (JIS A 5012 was integrated with JIS A 5011.) |
| 2002 | Blast Furnace Slag Aggregate Is Designated under Law on Promoting Green Purchasing for Public Works. |
| 2013 | Architectural Institute of Japan, Practice of Concrete with Blast Furnace Slag Fine Aggregate, An Application Method to High Strength Concrete Was Prescribed. |
| 2013 | A Rule of the Environmental Safe Quality and the Laboratory Procedure. |

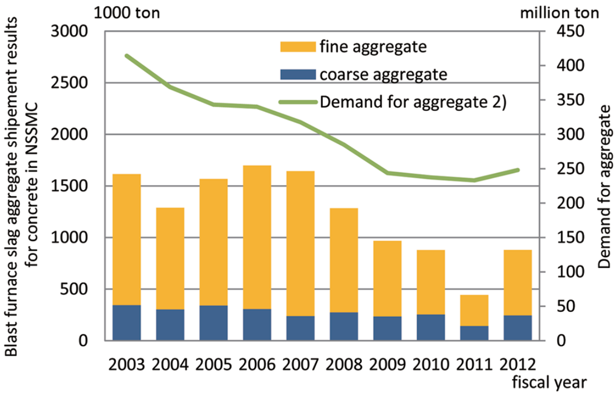


**Fig. 2 Company's shipment of BF slag aggregate for concrete**

Nippon Steel & Sumitomo Metal Corporation sold 1.5 million t of blast furnace slag aggregate (including in-house use) annually in the first half of the 2000s, but due to the latest fall in the demand for concrete aggregate (264 million t in 2011 [2]), the sale fell to below 1 million t (see **Fig. 2**), and it is now necessary to cultivate new fields of application of slag aggregate.

This paper presents the Company's latest activities to expand the use of BF slag aggregates quoting, as examples, the studies on the use of coarse BF slag aggregate for roller-compacted concrete for road pavement and promotion of the use of fine BF slag aggregate as a substitute for natural sand.

## 2. Application Technology for Coarse BF Slag Aggregate

### 2.1 Study on use of coarse BF slag aggregate for roller-compacted concrete paving

Concrete paving of roads is attracting attention recently because it is more durable than asphalt paving and offers lower life-cycle costs (LCC),[3] and use of recycled materials for concrete paving began to be studied to encourage the recycling of natural resources. Aiming at lowering the LCC of roads, the authors studied the applicability of coarse air-cooled BF slag aggregate for roller-compacted concrete paving (RCCP).

### 2.2 Materials used and mixing conditions

1) Target concrete performance

The design bending strength was set at 4.4 $N/mm^2$, the same as that for common RCCP, and including an additional strength of 0.8 $N/mm^2$ for compaction fluctuation and multiplying an overdesign factor of 1.09, the target mixing bending strength was set at 5.7 $N/mm^2$. According to the B072-2 "Test method of consistency of roller-compacted concrete" in the Pavement Inspection and Testing Manual, the fresh mix properties were examined using the vibrating compaction (VC) test method, and the mixing ratio was defined so that the corrected VC of as-rolled concrete would fall within the range of $50 \pm 10$ s.

2) Materials used

**Table 2** shows the materials considered in the study, and **Table 3** the physical properties of the aggregates used. Land sand from the city of Kashima, Ibaraki, was used as the fine aggregate, and coarse air-cooled BF slag from Kashima Works of the Company was used as the coarse aggregate.

3) Study of mixing ratio

Concrete was trial mixed in different ratios shown in **Table 4** using a laboratory mixer at a room temperature of 20°C. Here, the unit cement content was set at 280, 300 and 320 $kg/m^3$, and VC test was conducted on each of these specimens. Based on the VC test results and assuming that the transport time was 60 min, the mixing ratio was determined by defining the unit water content with which the corrected VC value after the 60-min transport time was 50 s. **Table 5** shows the results of bending strength test of the specimens prepared at the mixing ratios finally selected. The authors confirmed from the test results that the mixing ratio with which the bending strength of 28-day-old concrete attained the target value of 5.7 $N/mm^2$ was No. 3, where W/C was 35.9% and the unit cement content was 320 $kg/m^3$.

**Table 2 Materials used**

| Material | Symbol | Description | Density ($g/cm^3$) |
|---|---|---|---|
| Water | W | Tap water | — |
| Cement | C | Portland blast furnace slag cement (B) | 3.04 |
| Fine aggregate | S | Land sand | 2.63 |
| Coarse aggregate | G | Coarse BF slag aggregate | 2.60 |
| Admixture | Ad | AE (air entraining) water reducing agent (with a lignin sulfonic acid compound complex of the polyol) | — |

**Table 3 Physical properties of aggregates**

| Classification | | Density ($g/cm^3$) | | Water absorption (%) | solid volume (%) | Abrasion value (%) |
|---|---|---|---|---|---|---|
| | | $D_S$ | $D_D$ | | | |
| G | Coarse BF slag aggregate | 2.60 | 2.54 | 2.42 | 54.6 | 33.1 |
| S | Land sand | 2.63 | 2.59 | 1.47 | 68.0 | — |

$D_S$ : Saturated and surface-dry condition
$D_D$ : Oven-dry condition

Table 4 Mixing ratios studied for deciding unit water content

| No. | s/a (%) | W/C (%) | Unit quantity (kg/m³) W | C | S | G | Ad (C×%) |
|---|---|---|---|---|---|---|---|
| A-1 | 43.0 | 33.9 | 95 | 280 | 919 | 1 205 | 0.25 |
| A-2 | | 39.3 | 110 | | 902 | 1 182 | |
| A-3 | | 44.6 | 125 | | 885 | 1 160 | |
| B-1 | 43.0 | 33.3 | 100 | 300 | 906 | 1 188 | |
| B-2 | | 36.7 | 110 | | 895 | 1 173 | |
| B-3 | | 40.0 | 120 | | 884 | 1 158 | |
| C-1 | 43.0 | 32.8 | 105 | 320 | 893 | 1 170 | |
| C-2 | | 35.9 | 115 | | 882 | 1 156 | |
| C-3 | | 39.1 | 125 | | 870 | 1 141 | |

s/a : sand-total aggregate ratio

Table 5 Narrow list of mixing ratios

| No. | s/a (%) | W/C (%) | Unit quantity (kg/m³) W | C | S | G | Bending strength (N/mm²) 3 days | 7 days | 28 days |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 43.0 | 41.1 | 115 | 280 | 897 | 1 175 | 3.24 | 4.04 | 4.56 |
| 2 | 43.0 | 37.7 | 113 | 300 | 892 | 1 168 | 3.60 | 4.41 | 5.24 |
| 3 | 43.0 | 35.9 | 115 | 320 | 882 | 1 156 | 4.07 | 4.86 | 5.73 |

### 2.3 Confirmation of workability

To confirm the workability (i.e., mixing, transport, spreading, and compacting) of the RCCP using coarse BF slag aggregate and its performance under traffic loads (cracking, etc.), it was used for paving a road inside works premises of the Company as follows:

1) Date, place, paving conditions
- Date: Sunday, December 11, 2011
- Place: a road in the product yard of Kashima Works, Nippon Steel & Sumitomo Metal
- Dimensions: two lanes, each 5.65 m wide and 24 m long, with joints every 5 m
- Pavement structure: 20-cm thick surface slabs of roller-compacted concrete (RCC) containing coarse BF slag aggregate on 20-cm thick beds of iron/steel slag

2) Concrete mixing

According to No. 3 in Table 5

3) Outlines of paving work

The RCCP prepared using coarse BF slag aggregate was brought to the work site on a dump truck; during the transport, the concrete was covered with two layers of water-proof sheets to minimize water evaporation. A high-compacting asphalt finisher spread the RCCP at a speed of 0.8 m/min; the extra fill was 5% to 7%. After each of spreading, initial rolling, and finish rolling, the degree of compaction was measured using a scattering radio isotope density/moisture meter. The degree of compaction after the passage of the asphalt finisher was 96.3%, which evidences good compacting properties of the mix (see **Photo 1**).

The initial and secondary rolling were applied using a 8-t horizontal/vertical vibrating roller, and the finish rolling using a 8.5-t vibrating tire roller. The degree of compaction after the initial rolling was 97.5% and that after the finish rolling 99.8%, evidencing good compaction. A coating sealant was applied, curing mats were spread to cover the pavement surface, and water was sprinkled for curing; cut joints were formed the following day.

Photo 1 Concrete spreading by asphalt finisher

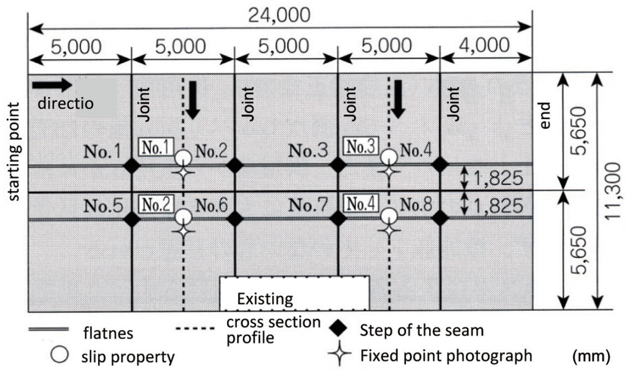


Fig. 3 Inspection and measurement points

Table 6 Flatness inspection

| Item | Inspection timing | 1 lane | 2 lanes |
|---|---|---|---|
| Flatness (mm) | Before placing in service | 3.33 | 4.23 |
| | After six months in service | 3.88 | 4.43 |

4) Results of quality control tests

As the quality control test before shipment to the work site, concrete specimens were subjected to the VC and bending tests. The corrected VC value was 36 s immediately after sample preparation, 51 s after 30 min, and 49 s after 60 min, and the bending strength was 5.9 N/mm² after 28 days of preparation, all of which satisfied the respective target figures.

### 2.4 Follow-up inspection

As the follow-up inspection of the RCCP, the following items were measured before placing the road in service and after six months of service: (i) flatness, (ii) cracking, (iii) level difference at joints, (iv) slip resistance, (v) cross-section shape, and (vi) fixed-point observation. The measurement points are given in **Fig. 3**.

1) Flatness

**Table 6** shows the results of flatness measurement. The flatness did not change substantially from immediately after paving to six months after placing in service: there was no deformation or change in flatness due to traffic loads. Note that the measurement accuracy depends on the length of the object, and it is considered that for meaningful flatness measurement, the object length must be 100 m or longer.[4] Since the length of this trial paving was as short as 24 m, the reading was larger than the commonly accepted standard of 2.4 mm, but it did not pose any problem for the traffic and was considered satisfactory.

2) Cracking

No cracking due to plastic contraction, which sometimes occurs at an early stage of curing, was found before the RCCP was put into service. Furthermore, no cracking of any structural significance was observed after six months of actual service.

3) Level difference at joints

No change in the joint level was found either immediately after paving or after six months of use.

4) Slip resistance

**Figure 4** shows the results of the measurement of British portable number (BPN) using a pendulum-type skid resistance tester; the graph shows the slip resistance values corrected to a road surface temperature of 20°C. The corrected BPN was above the target figure of 60 at every measurement point either before or six months after the placement in service. The BPN figures did not significantly change at any of the measurement points during the in-service period, and the RCCP is considered not to have degraded.

In addition, dynamic friction coefficient was measured with a dynamic friction (DF) tester before and after six months in service. The reading was better than the target value, 0.3, at every measurement point at speeds of 40, 60 and 80 km/h. The dynamic friction coefficient changed only a little before and after the six-month period,[5] and the performance was deemed not to have deteriorated at any of the measurement points.

**2.5 Summary**

The following results were obtained through studies and tests on the use of coarse BF slag aggregate for RCCP:

1) As a result of the mixing design for laboratory tests assuming a room temperature of 20°C and a transport time of 60 min from the mixing plant to the work site, the unit water content was set at 115 kg/m$^3$ and the unit cement content was set at 320 kg/m$^3$.
2) A corrected VC value of 51 s was obtained at actual paving work with the RCCP, and the bending strength of 5.9 N/mm$^2$ was attained after 28 days of casting, clearing respective target values.
3) The degree of compaction after compacting using a high-compacting asphalt finisher was 96%, the same after the initial rolling 97.5%, and that after finish rolling 99.8%, evidencing good compacting properties of the concrete.
4) No level difference at joints, no cracking or no significant change in slip resistance was found before and after the six-month period of service, which indicates that the performance of the concrete did not deteriorate.

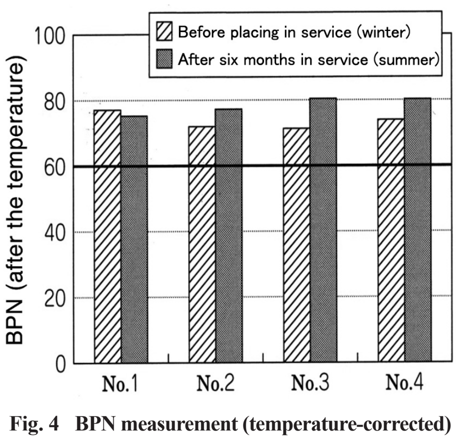


**Fig. 4 BPN measurement (temperature-corrected)**

The above results indicate that the use of coarse BF slag aggregate for RCCP did not pose any problem in its preparation, shipment, transport, and road paving. Periodical inspection will continue to accumulate more data on the performance change of the RCCP over time to evaluate the applicability of coarse aggregate of air-cooled BF slag and expand its use.

## 3. Application Technology for Fine BF Slag Aggregate

### 3.1 Problems in use of granulated BF slag as fine concrete aggregate

1) Fine BF slag aggregate is produced mostly through the cast house method, whereby molten slag tapped from a blast furnace is separated from hot metal by gravity separation and then granulated by water jet in the cast house; in some works, the granulation is done after receiving the slag in ladles and transferring it to a slag granulation plant. Since granulated BF slag tends to harden through hydrolysis (latent hydraulic property), it sometimes agglomerates depending on storage conditions. It is required to establish an economical storage method for preventing this from occurring before use.
2) By the latest practice, often two to three brands of natural or crushed sand are mixed to improve grain size distribution and used as fine aggregate for concrete. The JIS stipulations for fine aggregate of granulated BF slag provide for this, and specify four different grain sizes. While the use of mixed aggregate is left to the discretion of each user in consideration of applicable technical standards,[6] for encouraging the use of fine BF slag aggregate, it is important to accumulate technical data on its mixing considered the properties of natural aggregates and the crushed stone actually used in the region around slag producing steelworks.

### 3.2 Measures to help use of fine aggregate of granulated BF slag

To solve the above two problems in the use of granulated BF slag as fine aggregate for concrete, measures such as the following have been taken:

1) Measures to retard agglomeration

To slow down the agglomeration of fine BF slag aggregate, different kinds of agglomeration retarding agents are selected and sprayed at storage yards in consideration of the properties of the slag. Like cement, BF slag is considered to agglomerate as a result of the formation of CaO-SiO$_2$-H$_2$O, and in most cases, a suitable agent is selected through field tests from among the retarders for cement.[7]

On the other hand, studies have been made to quantitatively clarify the agglomeration retarding effects of retarders;[8] one such studies focused on sodium gluconate, and assuming that its solidification retarding effect was due to the Langmuir–Freundlich adsorption, formulated the effect using an adsorption isotherm formula and clarified the dependency of the retarding effect on the addition amount.

2) Study on grain size improvement of natural sand

When fine aggregates of BF slag are mixed with other types of fine aggregates, their mixing ratios locally vary from 10% to 60%.[9] To clarify the basic properties of concrete prepared at such widely varying mixing ratios, the authors are studying the relation between the mixing ratio and the slump, and the compression strength of the concrete by changing the ratio of fine BF slag aggregate from 20% to 80%.[10] It has been found so far that, although the mixing ratio of fine BF slag aggregate does not affect the slump and the compression strength, the volume ratio of total fine aggregate proportionately affects the slump.

### 3.3 Development of fine aggregate of air-cooled BF slag

1) Technical problems in the use of air-cooled BF slag as fine concrete aggregate

The following questions arise in relation to the use of air-cooled BF slag, less than 5 mm in grain size, as fine concrete aggregate: (i) whether the slag has the quality to meet the specifications under JIS A 5011-1 and (ii) since air-cooled BF slag is not approved by JIS as concrete aggregate, whether it is possible to market fine air-cooled BF slag as fine aggregate for concrete or cast concrete products.

The Company succeeded in commercializing air-cooled BF slag as fine aggregate by solving (i) above through improvement of the production process and (ii) by having air-cooled slag approved by relevant technical institutions as fine aggregate for cast concrete products and having such products approved by local governments as recycled products the purchase of which is recommended. These measures are explained below in more detail.

2) Improvement of slag production process

By the conventional production process of air-cooled BF slag, the percentage of fine powder tends to be too high to meet the required grain size distribution. As an improvement measure,

(a) wet vibrating screens and
(b) cyclone separators

were newly introduced (a and b being hereinafter collectively called the wet classification plant) to process crushed slag (grain size < 20 mm).

(1) Equipment configuration

The process flow in the wet classification plant is shown in **Fig. 5**. Wet vibrating screens 14 and 16 are provided to classify the crushed air-cooled BF slag, and wet cyclone separators 18 are provided to centrifugally classify the minus sieve from the wet screens.

(2) Wet vibrating screens

Fines form and segregate from larger grains during slag storage. To meet the quality requirement of grain size distribution, the wet vibrating screens are meant to wash and remove fines (see **Fig. 6**). The sieve opening is 2.5 mm.

(3) Cyclone separators

Cyclone separators are provided to treat the mixture of water and the minus sieve grains coming from the secondary wet screen (see **Fig. 7**). These cyclones separate fine aggregate from the slurry of the minus sieve smaller than 2.5 mm.

(4) Productivity

The wet classification plant, which was introduced to Wakayama Works, was confirmed through commercial operation to have a processing capacity higher than that of the old process that employed dry screens only.

3) Technical approval of fine aggregate of air-cooled BF slag

(1) Basic properties

**Table 7** shows the basic properties of the fine aggregate of air-cooled BF slag produced through the wet classification plant in comparison with JIS specifications. The fineness modulus and the content of grains finer than 75 $\mu$m of the product are better than those of conventional material, qualifying it as a JIS equivalent.

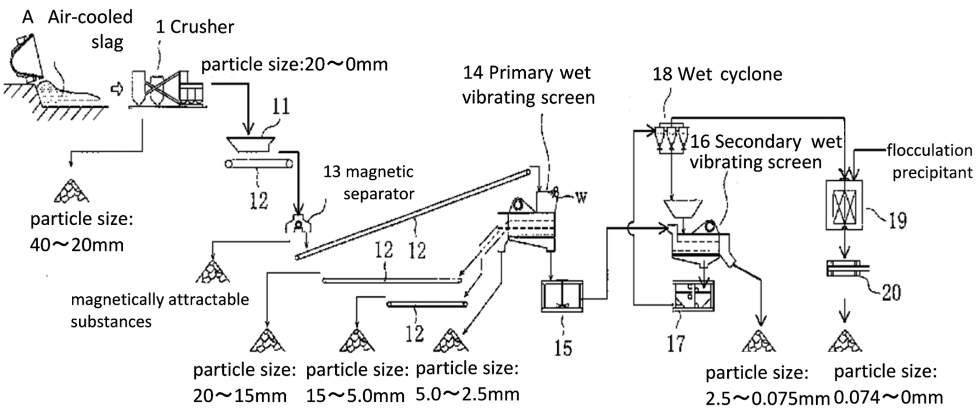


**Fig. 5 Process flow of wet classification plant**

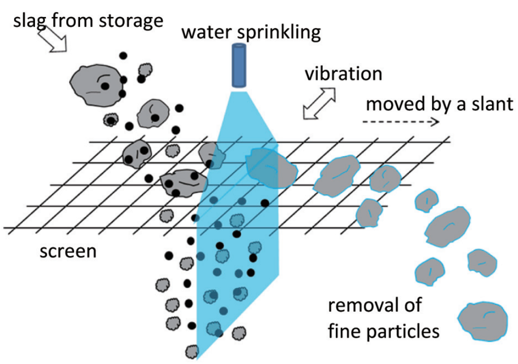


**Fig. 6 Classification by wet vibrating screen**

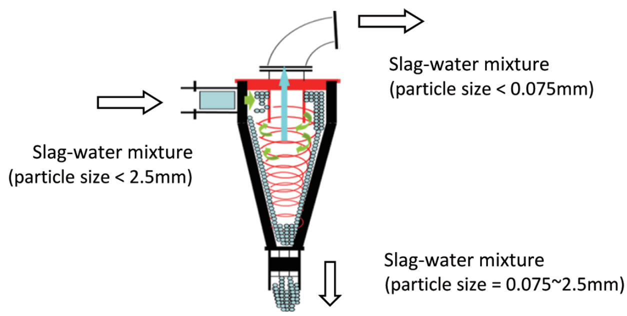


**Fig. 7 Cyclone centrifuge**

**Table 7 Comparison of air-cooled BF slag products with JIS specifications**

| Test items | | JIS A5011-1 (BFS2.5) | New product (wet screening) | | Reference (dry screening) | |
|---|---|---|---|---|---|---|
| | | | Evaluation | Value | Evaluation | Value |
| Fineness modulus | | Dispersion < ± 0.2% | ○ | < ± 0.1 (2.1 - 2.2) | × | ± 0.5 (2.3 - 3.3) |
| Mass of unit volume | (kg/l) | > 1.45 | ○ | 1.7 - 1.8 | ○ | 1.7 - 1.8 |
| Density in absolutely dry condition | (g/cm³) | > 2.5 | ○ | 2.75 - 2.81 | ○ | 2.82 - 2.88 |
| Water absorption | (%) | ≦ 3.5 | ○ | 1.7 - 2.6 | ○ | 1.2 - 2.7 |
| Finer than 75 $\mu$m | (%) | ≦ 7 | ○ | 3.8 - 6.4 | × | 9 - 14 |

Evaluation: ○ Good, × Poor

**Table 8 Chemical compositions of BF slag**

| Test items | | JIS A5011-1 (BFS2.5) | Fine aggregate of air-cooled BF slag | | Fine and coarse aggregate of BF slag | |
|---|---|---|---|---|---|---|
| | | | Evaluation | Value | Evaluation | Value |
| Chemical composition (%) | CaO | ≦ 45.0 | ○ | 38 - 42 | ○ | Avg. 42 |
| | S | ≦ 2.0 | ○ | 0.5 - 0.8 | ○ | Avg. 0.7 |
| | $SO_3$ | ≦ 0.5 | ○ | 0.10 - 0.44 | ○ | Avg. 0.3 |
| | FeO | ≦ 3.0 | ○ | 0.5 - 0.7 | ○ | Avg. 1.2 |

Evaluation: ○ Good, × Poor

(2) Chemical composition

**Table 8** shows the chemical composition of the fine aggregate of air-cooled BF slag produced through the developed process. Since the fine aggregate is the minus sieve coming from the process of the coarse aggregate, 5–20 mm in grain size, which has been produced and marketed according to JIS, there is no difference in the chemical composition.

(3) JIS registration as material for cast concrete products

According to JIS A 5011-1, fine BF slag aggregate is to be produced by rapidly cooling molten BF slag and controlling the grain size. On the other hand, the fine aggregate of the present development is produced using air-cooled slag as the raw material, and it does not conform to the JIS specification in terms of the production method. Considering this, Nippon Steel & Sumitomo Metal aimed at registering it as a material for cast cement products under JIS, and evaluated its quality as the fine aggregate for cast concrete products jointly with Wakayama Soft Concrete Cooperative and Nippon Steel & Sumikin Koka Co., Ltd. (now Nippon Steel & Sumikin Slag Products Co., Ltd).

(4) Quality evaluation results

i) Drying shrinkage

**Figure 8** shows the relation between the preservation period and shrinkage of cast concrete specimens. The fine aggregate of air-cooled BF slag proved to be excellent in drying shrinkage.

ii) Fresh concrete properties

The slump test was conducted to evaluate fresh concrete properties (workability, ease of mold dismantling, curing, etc.) using the fine aggregate, and the concrete proved to maintain adequate fluidity without aggregate segregation and fewer bleedings compared with ordinary concrete (see **Fig. 9**).

iii) Evaluation of cast concrete products

**Table 9** shows some items of the quality evaluation result of cast concrete products with respect to JIS specifications. The concrete with the fine BF slag aggregate proved satisfactory in terms of strength and other aspects of material performance.

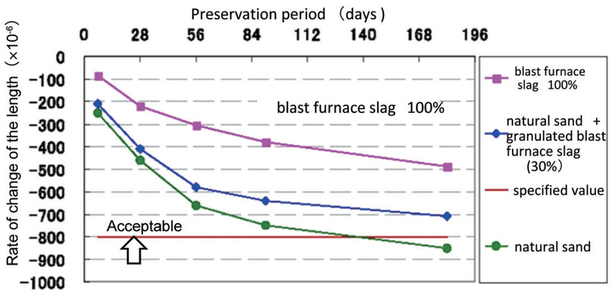


**Fig. 8 Concrete shrinkage with different aggregates**

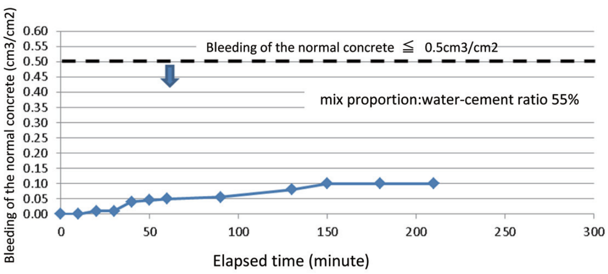


**Fig. 9 Relations of elapsed time and bleeding**

(5) Approval

As a result of the above quality evaluation, cast concrete products containing fine aggregate of air-cooled BF slag were accredited to satisfy relevant JIS specifications. This led to the approval of the products (with or without reinforcing bars) by the Wakayama Prefecture as recycled products on December 7, 2009, which consequently led to the increased use of various types of cast concrete products containing the aggregate for public construction projects. In addition, for this technology of the fine slag aggregate, the Company was awarded the Encouragement Prize for Resource Recycling Technology and System for the fiscal year 2012 by the Ministry of

**Table 9 Evaluation of cast concrete products (example: U-section gutter for street drain)**

| Item | Criterion | Evaluation | |
|---|---|---|---|
| Material strength | Compressive strength after 14 days of casting must be 24 N/mm$^2$ or more (JIS A 5372) | ○ | 38.0 N/mm$^2$ in average |
| Durability of cast products | Water/cement ratio must be 55% or less (JIS A 5364) | ○ | 49% (design water/cement ratio) |
| | Total alkali must be 3.0 kg/m$^3$ or less (JIS A 5308) | ○ | 2.2 kg/m$^3$ in average |
| | Chloride ions must be 0.30 kg/m$^3$ or less (JIS A 5364) | ○ | 0.04 kg/m$^3$ in average |
| Bending strength | There must be no cracks under a bending load of 16 kN (JIS A 5372) | ○ | No cracks under 18 kN |

Evaluation mark: ○ Good; △ Regular; × Poor

Economy, Trade and Industry.

### 3.4 Summary

1) Cement solidification retarder is effective at slowing down the agglomeration of fine aggregate of BF slag. It was known that its retarding effect can be numerically expressed using an adsorption isotherm formula, and based on this, it has been made clear that the time of retarding depends on its addition amount. In addition, the authors have found the basic properties of concrete prepared with fine aggregate of BF slag together with other types of aggregate; such findings include, for example, that the slump changes in direct proportion to the volume ratio of total fine aggregate.
2) The introduction of the wet classification plant has made it possible to produce fine aggregate of air-cooled BF slag satisfying relevant JIS specifications. Cast concrete products for which the fine aggregate was used were officially accredited to conform to JIS specifications, which made their marketing viable.

## 4. Closing

The present paper has presented the latest activities of Nippon Steel & Sumitomo Metal to expand the uses of BF slag for concrete aggregate applications.

It has been more than 30 years since the aggregate of BF slag for concrete was included in JIS. Use of BF slag for the application has accumulated in the meantime and its advantages as a construction material have been widely recognized, but to encourage its wider use, it is essential to develop new applications in cooperation with users. To better respond to future social requirements of efficient use of natural resources, it is necessary for the steel industry to continue cultivating new fields of use of and demand for slag as well as renovating its processing methods.

**Acknowledgements**

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