Technical Report

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Overview of Slag Usage Technology Development at Various Works

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Abstract

Nippon Steel & Sumitomo Metal Corporation has eight integrated iron and steel works with blast furnace in the whole country of Japan, and each manufacturing process is different based on the several kinds of specific steel productions. Slag treatment processes about cooling, clashing and sizing are also originated in each works inevitably. So slag products produced from each steelworks are very different in the chemical components, the solidification and/or the mineral-phase. Even in the relation between supply and demand, and requirement (needs) from the customer are also different from the regional market around each steelworks. As a company-wide challenge, Nippon Steel & Sumitomo Metal Corporation has developed incessantly the original slag products depending on each characteristic slag, which have not only the innovated function or new seeds, but also the adaptability to the severe social compliance. In this report, we have summarized our developing status of the process and products for slag usage at the forefront of every steelworks.

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1~8 A figure of 1~8 shown at the right side shoulder of an author's name denotes the number of the chapter of his authorship in this report.

1. Examples of Slag Usage Development at Muroran Works
—Study on Heavyweight Concrete Using Steelmaking Slag as Aggregate—

1.1 Introduction

Soon, one year will pass (at the time when this project was proposed) since the Great East Japan Earthquake occurred, and retrieval and reconstruction from the earthquake are now entering the phase of constructing specific plans and then going to the implementation stage of various construction works. It is foreseen that in conjunction with the progress of construction works, the demand for concrete, a major construction material in these construction works, will rapidly grow, and consequently, a tremendous volume of aggregate materials will be needed. However, the production and consumption of concrete aggregates take the distribution form of "locally produced, locally consumed" type in a relatively limited regional area. Therefore, production facilities of aggregates suffer from devastation when they are located in disaster-stricken areas or when workers of such facilities take shelter in remote areas. Such situations make it difficult for aggregate producers to supply materials appropriately to the growing demand. Then, the utilization of by-products produced in various industries (recycling) is conceivable; however, it is not easy to secure a material that satisfies the required quality when it is used as a concrete aggregate and furthermore guaranteed with the capability of a massive and stabilized supply.

Because the scale of tsunamis exceeded the level set in the past, in the retrieval and reconstruction works, the construction of structures with the stability against tsunamis and waves far exceeding this level is demanded. To realize this, although measures of constructing structures larger in size than the ones before or constructing structures of the same size with greater weight using heavyweight concrete are conceivable, the construction of such structures using conventional technologies and materials only results in a great increase in construction cost.

To cope with the above two problems, in this project, study on the mixing ratio of a steelmaking slag for use as a concrete aggregate and the construction of concrete structures using such concrete are conducted. Specifically, steelmaking slags produced in steelmaking refining processes have been scarcely used as concrete aggregates, unlike blast furnace slags. However, the utilization of steelmaking slags as substitutes for natural aggregates can be expected because it has constant quality and is characterized by the capability of a stabilized and massive supply. Furthermore, because the specific weight of a steelmaking slag is larger than that of natural aggregates, there is a possibility of massive production at a lower cost of concrete that is appropriate for heavyweight concrete structures with a higher stability against tsunamis and waves. This project aims to establish an optimum mixing ratio of concrete that exerts the maximum effect and substantiate technologies that promote restoration works efficiently with limited sum of budget by constructing concrete structures using a ready-mixed concrete plant and the like located in disaster-stricken areas.

1.2 Main subject

To utilize a steelmaking slag as a concrete aggregate, it is important that the workability and characteristics such as hardening characteristics of the so-produced ready-mixed concrete are equivalent to those of conventional concrete using natural aggregates. Furthermore, in the development of heavyweight concrete by taking advantage of the characteristics of a larger specific weight of a steelmaking slag, in addition to the specific weight of concrete, other characteristics equivalent to those of conventional concrete are demanded.

In this regard, in this project, substantiating research was performed over the basic items for grasping as follows: physical properties of a steelmaking slag, optimum mixing condition appropriate for concrete where a steelmaking slag is used as an aggregate, and various performances and characteristics in detail. Adaptability of a steelmaking slag to a concrete aggregate is assessed based on the results of the items as follows.

1) Physical property test of a steelmaking slag for use as an aggregate
2) Study on mixing ratio for the use of a steelmaking slag as an alternate concrete aggregate
3) Production test in an actual plant and workability test of heavyweight concrete using a steelmaking slag as an aggregate
4) Summarization

Details of the above are given below.

1.2.1 Physical properties test of steelmaking slag for use as an aggregate

To grasp physical properties and characteristics of a steelmaking slag for use as an aggregate, various physical property tests were performed (**Table 1.1**). In addition to generally conducted tests for particle size distribution and powdering rate, the relation between steam aging condition and the amount of hydration expansion and the relation between particle figure and particle size distribution during sieving in the production of fine aggregates were again assessed afresh, and conditions for securing quality of a concrete aggregate were arranged. A part of the result is given below.

1.2.1.1 Expansion stability test of steelmaking slag for use in an aggregate

A steelmaking slag develops hydration reaction when its free CaO and free MgO come into contact with water, characterized by the expansion of its volume due to the reaction. In this hydration reaction, in the temperature range up to several hundred °C, the higher the temperature, the faster is the reaction. Therefore, in steelworks such as Muroran Works, a slag is shipped out for use as road base course material and so on after a stabilization treatment is performed

Table 1.1 Method of measurement

Measurement items	Method of measurement
Particle size	JIS A 1102-1103
Unit capacity mass	JIS A 1104
Density and water absorption	JIS A 1109 and JIS A 1110
Powdering rate	Steel slag hydrated solidificed body technique manual
Chemical composition	
Rate of expantion	JIS A 5015
Resistance to abrasion of coarse aggregate	JIS A 1121

Photo 1.1 Method of measurement

Photo 1.2 Test equipment

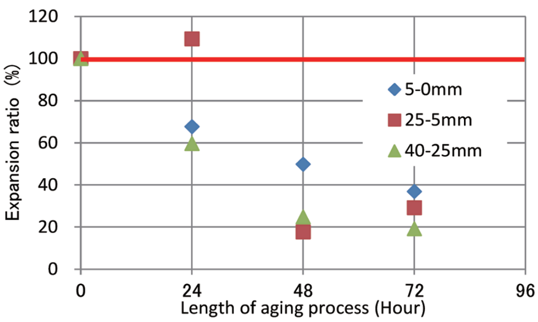

Fig. 1.1 Rate of expansion

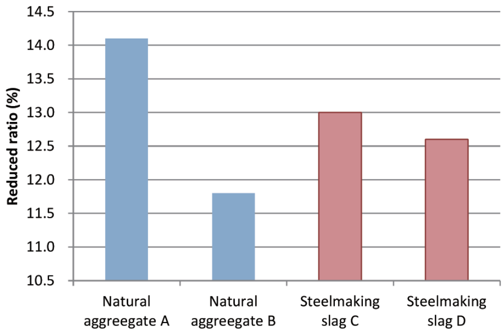

Fig. 1.2 Resistance to abrasion of coarse aggregate

by a steam aging treatment.

Here, to investigate the relation between aging treatment time and expansion of a steelmaking slag after the completion of the treatment, an expansion stability test for the use of the slag in a road aggregate (JIS A 5015) was conducted. The test method is as follows: aging treatment tests for 24, 48, and 72 hours were conducted, containers filled with a steelmaking slag so treated were immersed in water of 80°C (**Photo 1.1**), the expansion of a steelmaking slag was promoted thereby, and then, the amount of expansion was measured by a dial gauge installed on the top of the container. As immersion condition, the container was immersed in water of 80°C for 6 hours a day, and this immersion was repeated for 10 days.

As a result of the test, it was confirmed in the expansion stability test that the longer the steam aging treatment time, the smaller is the amount of the expansion of a steelmaking slag and that the expansion by hydration reaction converges to approximately one expansion ratio at the aging treatment time of 72 hours (**Fig. 1.1**). However, even when aging treatment processing for 72 hours is performed, the expansion of a steelmaking slag cannot be suppressed entirely. Therefore, it is considered that in the application to concrete where the expansion of an aggregate possibly exerts influence over the quality of concrete, appropriate quality control of the aggregate and the selection of appropriate usage of concrete become necessary.[1)]

1.2.1.2 Test for resistance to abrasion of an aggregate

In case of a brittle aggregate that may fragment during transportation or kneading in a concrete mixer, particle size distribution during shipment from a plant becomes varied greatly, and desired concrete quality is not obtained. Therefore, a sufficiently high hardness is required such that a concrete aggregate does not undergo any fragmentation and abrasion easily. Here, resistance to the abrasion of a steelmaking slag aggregate was investigated with the test method for resistance to the abrasion of a coarse aggregate using Los Angeles machine (JIS A 1121). For comparison, a natural aggregate actually used for concrete was employed.

In the test method, steel balls of 46.8 mm in diameter and an aggregate were thrown into the test equipment (**Photo 1.2**), and after the required number of rotations of the equipment, weight percent of the aggregate that passes through a sieve of a mesh of 1.7 mm (amount of abrasion loss) is sought for. From the result of the test, it was confirmed that a steelmaking slag aggregate possesses resistance to abrasion almost equal to that of a natural aggregate (**Fig. 1.2**).

1.2.2 Study on mixing ratio for use of steelmaking slag as alternate concrete aggregate

Supply condition of a natural aggregate varies depending on regional and seasonal conditions. Therefore, the possibility of the optional selection of a combination of aggregates depending on required condition is important, i.e., selecting either the case of replacing only coarse aggregates or only fine aggregates with a steelmaking slag or the case of replacing both coarse aggregates and fine aggregates with a steelmaking slag. In the test, cases of the combination of aggregates were assumed and the mixing ratio that satisfies quality required for concrete (fresh concrete properties, hardening characteristics) was studied.

In the test for hardening characteristics, compressive strength and bending strength were confirmed; moreover, resistance to freezing and thawing from the viewpoint of the durability of concrete using a steelmaking slag as an alternate aggregate, amount of drying contraction, carbonation rate, and salt penetration depth were directly measured. In addition, the observation of a change in microstructure was attempted by measuring the distribution of the pore diameter from 2.5 nm to 10 μm (**Table 1.2**). Furthermore, dissolution test was performed to assess the influence of the obtained concrete over environment. A part of the test result is given below.

1.2.2.1 Mixing test

Properties and hardening characteristics of concrete during the

Table 1.2 Method of measurement

Measurement items	Method of measurement
Slump	JIS A 1101:2005
Air volume	JIS A 1128:2005
Concrete temperature	Bar thermometer
Characteristics	Visual
Compressive strength	JIS A 1108:2006
Bending strength	JIS A 1106:2006
Freezing and thawing	JIS A 1148:2001
Length change	JIS A 1129-3:2001
Carbonation	JIS A 1153:2003
Salt penetration depth	JSCE-G 572-2007
Damage by expansion of steelslag	Steel slag hydrated solidificed body technique manual
Dissolution	Criterion on bottom earth and sand (Ministry of the Environment Notification #14) etc.
Pore structure	Mercury penetration method

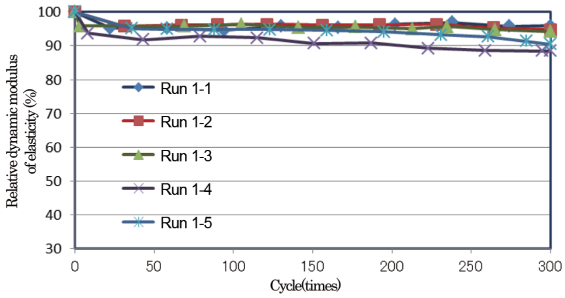

Fig. 1.3 Result of freezing and thawing test

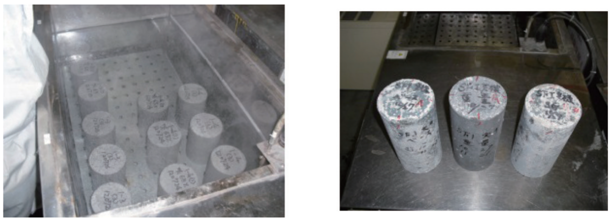

Photo 1.3 Expansion test of concrete

completion of kneading subtly vary depending on aggregate, water, type of a chemical admixture, and mixing ratios. Therefore, to establish the mixing condition that satisfies the quality, which allows the use of a steelmaking slag aggregate, numerous tests in which mixing condition was varied was performed based on which properties of concrete using a steelmaking slag aggregate were grasped and the optimum mixing ratio satisfying the condition for use were selected. As a result, it was confirmed that by properly modifying the mixing conditions such as fine aggregate ratio and unit water volume, fresh concrete properties equivalent to those of concrete using a natural aggregate could be obtained.

1.2.2.2 Freezing and thawing tests

The factor that generally indicates the resistance to freezing and thawing is the value of relative dynamic modulus of elasticity, and the value of 60% or above at the 300th cycle of freezing and thawing needs to be secured. It was confirmed that the durability of the resistance to freezing and thawing of concrete using a natural aggregate and of concrete using a steelmaking slag with each mixed under respective conditions satisfies the required performance (**Fig. 1.3**).

1.2.2.3 Expansion stability test

An expansion stability test of concrete was conducted based on the manual for steel slag hydrated matrix technology. In the test, concrete test samples are immersed in water of 80±3°C for 10 days incessantly, and then, the surfaces of the samples are checked for any abnormalities such as cracks (**Photo 1.3**). As a result of the test, no such abnormalities were found and no problems were caused in concrete by the steelmaking slag aggregate used. Therefore, as mentioned above, although the expansion of a steelmaking slag aggregate cannot be entirely suppressed even by the steam aging treatment of 72 hours, it was confirmed that the processing can stabilize expansion to the extent where a steelmaking slag is usable as a concrete aggregate.

It was confirmed that the results of other tests pertaining to various hardening characteristics such as compressive strength, salt penetration, and pore structure showed no adverse effects exerted by the use of a steelmaking slag aggregate. On the other hand, concrete using a steelmaking slag aggregate displayed a preferable smaller amount of drying contraction with a somewhat inferior degree of carbonation when compared with that of conventional concrete using a natural aggregate.

To investigate the influence of a steelmaking slag on the surrounding environment, a dissolution test was conducted. The test procedure for a construction material that uses iron and steelmaking slags and a steel slag hydrated matrix was employed for this purpose, and assessment was conducted on the basis of the criterion on bottom earth and sand (Notification #14, Ministry of the Environment) and the environment-related JIS (JIS K 0058-1 and -2). In all items analyzed, the measurement results were within criteria, and no adverse influence of the used steelmaking slag over the environment was confirmed.

1.2.3 Study on mixing ratio for developing heavyweight concrete

We tackled the study on the mixing ratio of concrete to increase its specific weight and develop heavyweight concrete by further studying the mixing ratio using a steelmaking slag aggregate, where the aimed specific weight of heavyweight concrete was set at 2.5–2.7 (unit volume mass 2.5–2.7t/m^3).

To develop heavyweight concrete, it is necessary to reduce the quantity of water, which has the lowest specific weight among concrete materials, to the minimum extent possible and to contrarily increase the quantity of a steelmaking slag aggregate, which has the highest specific weight. Because the resistance of concrete to separate from other materials and/or chronological deterioration in stability are anticipated, for a simultaneous solution of problems, the selection of a chemical admixture for concrete and its development were started, followed by the study on the mixing ratio of concrete and measurement of hardening characteristics.

As a result of this test, it was found that to secure excellent properties of concrete using a steelmaking slag aggregate, the use of a chemical admixture different from the one for concrete using a natural aggregate became necessary. Furthermore, in the mixture of heavyweight concrete where the reduction of unit water quantity is required, the trend was remarkable. In this research, a new admixture was developed and the mixing condition that satisfies the aimed fresh concrete properties and unit volume mass (2.5–2.7t/m^3) was

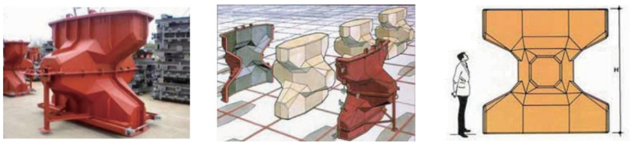

Fig. 1.4 Wave-dissipating concrete block

Photo 1.4 Concrete placing situation

Photo 1.5 Form removal situation

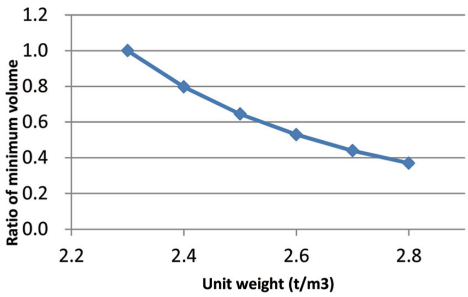

Fig. 1.5 Unit weight and ratio of minimum volume

established. Various hardening characteristics were confirmed to ensure the applicability of the so developed concrete to heavyweight concrete.

1.2.4 Tests of concrete production in actual plant and actual construction

Two types of mixing ratios were selected from among the test results obtained in a laboratory test, and the final assessment was performed through actual production and construction tests in the ready-mixed plant in Minamisoma City.

In the premise of KATOKENZAIKOGYO Co., Ltd., the actual test of the pouring of concrete to the formworks of a wave-dissipating concrete block and a reinforced beam-type structure was performed. The specification of the wave-dissipating concrete block was of the 6.3 m^3 of AKUROPOD® type produced by Tohoku Pole Corporation (**Fig. 1.4**), and the specification of the reinforced beam-type structure was of the D13@200 type, 50 cm in height, 50 cm in width, and 3 m in length, for which three types of concrete, i.e., "conventional concrete" using only a natural aggregate; "concrete using an alternate material for a coarse aggregate," wherein only a natural coarse aggregate was substituted with a steelmaking slag; and "heavyweight concrete," wherein both natural coarse and fine aggregates were substituted with a steelmaking slag, were poured into respective formworks.

A steelmaking slag produced at Muroran Works was transported to the ready-mixed concrete plant of KATOKENZAIKOGYO Co., Ltd., in Minamisoma City on October 23rd 2012, and concrete production and pouring test were performed on October 27th 2012 (**Photo 1.4**). Results of the test showed no difference in pouring operation because of difference in types of concrete aggregates, and in any concrete using different aggregates, pouring operation was satisfactory. Furthermore, on November 1st, five days after pouring, the formworks were detached and no defects such as cracks were found on the surface of the respective concrete structures (**Photo 1.5**).

1.2.5 Usefulness of concrete using steelmaking slag as aggregate

Different from the unit volume mass of 2.3 t/m^3 (≒specific weight 2.3) for general conventional concrete, the unit volume mass obtained in the substantiating test was 2.5 t/m^3 for concrete using an alternate coarse aggregate and as high as 2.7 t/m^3 for heavyweight concrete. The usage that can utilize the characteristics most effectively is for wave-dissipating concrete blocks and the like of harbor structure.

1.2.5.1 Stability against waves

The minimum mass of a wave-dissipating concrete block against waves of a certain scale can be sought for by the Hudson formula of "Technical criterion・explanation for harbor structure (supervised by Ports and Harbors Bureau of Ministry of Land, Infrastructure, Transport and Tourism)".[2] According to the formula, by the effect of seawater buoyancy and so on, when the unit volume mass of concrete becomes 1.13 times (=2.6/2.3) larger, the minimum mass (size) required for a block is reduced to almost half (0.53 times) and a very large effect is produced (**Fig. 1.5**). Furthermore, in case of a block of the same size, mass safety coefficient against waves of a scale can be increased by two times, where mass safety coefficient means the actual weight of a concrete block against the required block weight for waves of a scale.

In general harbor and marine structures such as artificial reef, the minimum required scale of structure is provided depending on the sea depth where concrete blocks are to be installed. Although it is considered that there are few cases wherein the number of concrete blocks can be drastically reduced owing to a higher unit volume mass (≒specific weight) of concrete, it can be said that there are many cases in which mass safety coefficient is greatly enhanced.

1.2.5.2 Cost of concrete

Peridotite, for instance, is cited as a natural aggregate for heavyweight concrete. The cost of such an aggregate is high, and therefore, fresh heavyweight concrete using such a natural aggregate is more costly than fresh conventional concrete by about 1.5 times. On the other hand, a steelmaking slag aggregate, although dependent on transportation distance and method of steelworks, are made available at a cost almost equal to that of a general natural aggregate, and therefore, a substantial reduction in raw material cost is possible in case a steelmaking slag is used for heavyweight concrete as an aggregate.

1.2.5.3 Scarcity in natural aggregate having large specific weight

Aforementioned peridotite and the like are used as a reforming material for sintering a material in steelworks and are used in various industrial fields. However, deposits are limited. Therefore, it is considered that the utilization of a steelmaking slag, a by-product in steelmaking refining process, as a concrete aggregate, substituting such a scarce natural material, has the possibility of providing ripple effects not only to concrete but also to broad fields.

From the above, it can be said that concrete using a steelmaking slag as an alternate aggregate developed in this project can become a very effective construction material as an aggregate of heavyweight concrete.

1.3 Conclusion

Although through various tests and studies performed in this project, it can be judged that concrete using a steelmaking slag as an alternate aggregate can be used for conventional concrete and heavyweight concrete; the belowmentioned subjects need to be further studied hereafter for application to practical use.

(1) Comparison of properties with that of conventional concrete (to be continued)

(2) Quality control
Method of controlling scattering in the particle distribution of a steelmaking slag aggregate

(3) Sales promotion
Activities directed toward the Ministry of Land, Infrastructure, Transport and Tourism, local governments, and contractors for recognition and authorization

Two years have passed since the Earthquake occurred (at the time of editing the project report), and numerous retrieval and reconstruction works are being planned and implemented; however, a shortage of concrete aggregates, a major material for such construction works, has surfaced. Model calculation and voices from aggregate suppliers tell that this trend will go far tighter hereafter. Furthermore, not only in disaster-stricken areas but also in disaster prevention countermeasures promoted in other areas of Japan, it has become increasingly important to efficiently construct structures with enhanced stability against waves to protect coastal areas. Under this type of situation and demand, to exercise the product accomplished in this project as early as possible and to the maximum extent possible, Nippon Steel and Sumitomo Metal and Flowric Co., Ltd., both having strongholds nationwide, will continue to cooperate with each other hereafter for the promotion of problem–solution and sales under the direction of Professor Hisada of Tohoku University, who plays a key role in the field of concrete material, and make efforts to contribute to the retrieval and reconstruction of areas stricken by the Great East Japan Earthquake and to the development of nationwide disaster prevention countermeasures.

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2. Introduction of Slag Usage Technologies at Kashima Works

2.1 Introduction

Kashima Works—favored by the blessing of the Tone River, famously called “Bando Taro”—is an integrated steelworks constructed in the Kashima coastal industrial zone on the coast of the Sea of Kashima in the south east area of Ibaragi Prefecture. The annual production of crude steel in fiscal 2013 was approximately 7 million tons, and the amount of a steel slag produced was about 2.8 million tons, which is almost equal to the total steel products in terms of volume, judging from the volume rate. For the slag of such a large volume, the steelworks is making an incessant daily study on the sales of slag products with added value.

Ibaragi Prefecture follows Hokkaido and Aich Prefecture in terms of overall road occupancy area,[3] and the steelworks, by taking advantage of its location that the distance to major cities such as Tokyo and Chiba is about 100 km, has developed and is selling slag products mainly for road bed material use in land civil engineering works.

Careful attention to performance for the environment of slag products is indispensable for the development of reliably usable products and is a very important access to and threshold of steady business. Furthermore, although a slag is used as a useful resource, in consideration of the influence of environmental conservation when the slag is reused after end of life, the amount of slags produced per ton of steel should be little.

This study introduces the examples of how the development of slag products produced at Kashima Works contributes to environmental conservation and how a slag generated per ton of steel was reduced under the overall cooperation of ironmaking and steelmaking divisions.

2.2 Examples of improvement technology of the environmental issue

2.2.1 Example 1 (Fluorine elution restraining technology)

Production of a slag for use as a road base course material was started based on JIS A 5015 stipulated in 1979, and thereafter, numerous improvements were made to the performance of the products of which results were incorporated into JIS. In the JIS revised in 2013, environmental safety quality standards were incorporated

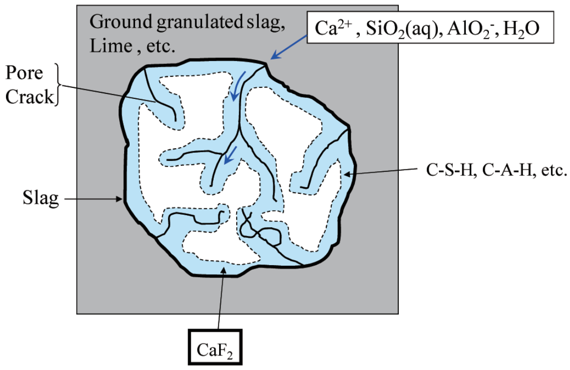


Fig. 2.1 Fluorine elution restraint mechanism

to produce more secure products. At Kashima Works, since before the incorporation to the standard, technologies that comply with environmental safety quality standards had been developed, and as one of the examples of such technologies, fluorine elution restraining technology is introduced.

In refining molten pig iron, to promote the removal of impurities, fluorite (CaF_2) was applied sometimes. However, fluorine (F) was eluted from a slag when fluorite was applied, which caused concern to the environment. To cope with the problem, a production method of slag products wherein environmental performance is secured by restraining the elution of fluorine even if fluorite is used to a certain extent and the development of a refining process without using fluorite were promoted.

(1) Fluorine elution restraining technology

Fluorine elution is restrained by fixing fluorine with hydrate having high fluorine fixation ability, which is intentionally produced by mixing and kneading fluorine-containing steelmaking slag and silica-eluting materials such as granulated blast furnace slag and burnt lime (**Fig. 2.1**).[4] This is a technology in which calcium ions eluted from a slag react with silica and form particular hydrate and fix fluorine; in addition, excessive calcium ions that burnt lime elutes fix fluorine in the form of calcium fluoride. Moreover, because a refining process that does not apply fluorite was established in parallel with this technology, the road base course material produced by this technology is no longer sold.

2.2.2 Example 2 (Soil improvement: Technologies for restraining elution of heavy metals from soil)

A technology of restraining elution of heavy metals from soil by taking advantage of alkaline characteristics of iron and steelmaking slags is introduced.[5]

Often, soil contains naturally heavy metal elements such as manganese, zinc, arsenic, cadmium, and nickel. In case of the soil being neutral, they are not eluted and are harmless. However, when the pH of soil shows acidity, these heavy metals are eluted and are a concern for environmental contamination, and the growth inhibition of agricultural products emerges. For example, the soil of Amami-oshima is acidic with a pH of 5.1 and has the risk of eluting heavy metals.

This soil can be stably neutralized for a long time by mixing soil and iron and steelmaking slags sized to below 30 mm. **Table 2.1** shows an example of experiments, and it is found that elution amounts of manganese and zinc are reduced by neutralizing the pH of soil by applying a slag. It is possible to adjust the pH to a desired value by adjusting the mixing amount of slags depending on land use purpose and soil compositions. Furthermore, as calcium dissolves slowly, it is possible to maintain the pH for a long time. This is an example showing that alkalinity becomes a problem for the use such as a slag ballast, therefore, the use of slag products is sometimes restricted; however, it serves the purpose of improving the environment by taking advantage of its drawback skillfully. In addition, a slag contains phosphoric and silicic acid, iron, Mg, Ca, and so on, which are useful ingredients for vegetation, and the use of a slag as a fertilizer is also expected.

Table 2.1 Influence of pH on heavy metal elution amount

pH in soil	5.1	7.8	8.9	10.4	11.8	13.1
Elution amount of zinc (mg/l)	300	42	0.06	0.6	6.5	243
Elution amount of manganese (mg/l)	245	252	2.4	0.08	0.1	0.05

2.3 Promotion of reuse of slag in a circulating manner in steelworks

At Kashima Works, the reduction of a slag generated in iron and steelmaking processes is being tackled. As reduction methods, conceivable are; to reduce the amount of use of flux and to reuse slag generated. Hereunder, an example of reusing the slag generated in a steelmaking process in a blast furnace and the steelmaking process are introduced.

Here, two steelmaking processes are employed to counter to deterioration in material quality and to satisfy the processing of high-quality steel. The process of the removal of impurities through desulfurization, dephosphorization, and decarburization is conducted in two or three stages.

Slag generated in the desulfurization process contains ingredients of high contents of iron and lime. Although these ingredients are useful in ironmaking processes, the slag is unusable in the steelmaking process because of the high concentration of sulfur. Thus, a process was designed wherein a slag is reused at a sintering process and sulfur is separated from the raw material in the form of SO_x by combustion and then recovered, being contained in a plaster at the waste gas treatment station; therefore, not only iron but also lime together with sulfur can be recovered. With this process, the slag generated in the desulfurization process is reused in steelworks approximately by 100%.

Furthermore, in the three-stage steelmaking process, the slag generated in the decarburization process after the dephosphorization process contains a low content of phosphor but rich contents of iron and lime. Therefore, it can be reused at the sintering and steelmaking processes by crushing it to an appropriate particle size and then sizing it. The slag generated in the decarburization process after the dephosphorization process is also reused in steelworks approximately by 100%.

As a result of these activities, 230 thousand tons of a steelmaking slag is reused within iron and steelmaking processes annually, contributing to a reduction in the consumption of natural resources (**Table 2.2**).

2.4 Conclusion

As the examples show, the development of technologies for improving the environmental performance of iron and steelmaking slag products has been introduced. Improvements in the environmental performance of slag products and the reduction of the amount of slag generated per ton of steel contribute to environment conservation. Moreover, iron and steel products continue to repre-

Table 2.2 Reusing amount

Fy	Reusing amount (kt/Fy)
2009	206
2010	245
2011	259
2012	232
2013	231

sent products with a reduced environmental load; authors are determined to continue developing technologies to make slags become environmentally harmonious-type products.

3. Slag Usage Development at Kimitsu Works

3.1 Introduction

Kimitsu Works is an integrated steelworks situated in the middle of Boso Peninsula, facing the Bay of Tokyo, and produces and sells about 4 million iron and steelmaking slags. Similarly, In the domestic general slag usage,[6] much of the blast furnace slag is used mainly for cement material, concrete aggregate, and road base course material, and much of the steelmaking slag is used for road base course material, soil improvement, artificial stone, and so on; the development of production method appropriate to Kimitsu Works and the development of usage satisfying customers' needs have been performed. This study introduces the cases of a blast furnace slag fine aggregate and the application of soft ground improving technology to explain the current status of slag usage at Kimitsu Works.

3.2 Blast furnace slag fine aggregate

3.2.1 Functions required to fine aggregate for concrete

Securing fresh concrete fluidity is the most important function for a ready-mixed concrete aggregate, and therefore, securing the required particle distribution and large unit volume mass is required. However, in recent days, a sole type of a material having proper particle distribution cannot be found among natural sands such as sea sand and mountain sand; therefore, proper particle distribution is arranged by blending materials of different particle sizes.[7] In the neighborhood of Kimitsu Works, relatively fine mountain sand is mainly available; therefore, coarse aggregate is sought for.

3.2.2 Production technologies of blast furnace slag fine aggregate

After being tapped from a blast furnace, the blast furnace slag is separated from molten pig iron because of the difference in its specific weight; the slag is then either water-granulated in the close vicinity of a blast furnace (slag processed in such a manner is hereafter called as furnace-site-granulated blast furnace slag), or tapped to a slag ladle, transported to another site, and then water-granulated (slag processed in such a manner is hereafter called as off-furnace-site-granulated blast furnace slag).

As observed in both the abovementioned slags, needle-shaped particles intermingle with particles of other forms after a water-granulation treatment (**Fig. 3.1**); however, in case they are used as a fine aggregate for concrete, these needle-shaped particles lower the unit volume mass and inhibit the fluidity of fresh concrete. Therefore, a grinding treatment is applied; the needle-shaped particles are ground (**Fig. 3.2**), and then, the slag is shipped out. Furthermore, for the adjustment of particle size, fine particles are sometimes classified as necessary.

An off-furnace-site-granulated blast furnace slag is coarse and heavy even after grinding, whereas a furnace-site-granulated blast furnace slag is somewhat fine and light. On the other hand, the production amount of a furnace-site-granulated blast furnace slag is higher, and thus, the establishment of a production method of fine aggregates using the mixture of a furnace-site-granulated blast furnace slag and an off-furnace-site-granulated blast furnace slag was necessary. Then, change in particle distribution and unit volume mass of the mixture was investigated by changing the mixing ratio of a grinding-treated furnace-site-granulated blast furnace slag and a grinding-treated off-furnace-site-granulated blast furnace slag. As a result, a mixing condition that satisfies the required specification stably could be found, and an optimum production system that satisfies the demand was established, wherein a furnace-site-granulated

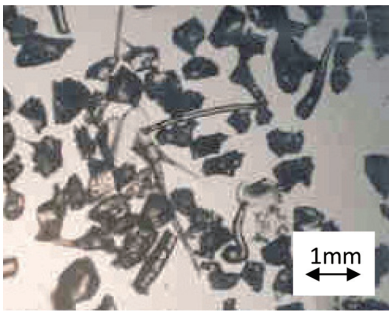


Fig. 3.1 Granulated blast furnace slag before the crashing processing

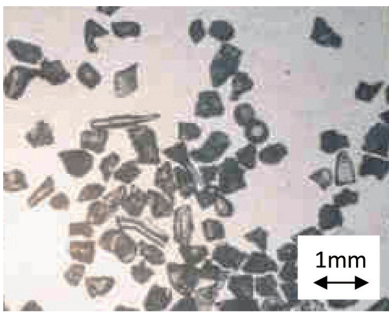


Fig. 3.2 Granulated blast furnace slag after the crashing processing

blast furnace slag without the grinding treatment is shipped for cement, a grinding-treated furnace-site-granulated blast furnace slag is shipped solely for fine aggregates of fine mesh, and a mixture of a grinding-treated furnace-site-granulated blast furnace slag and grinding-treated off-furnace-site-granulated blast furnace slag is shipped for fine aggregates of coarse mesh (**Fig. 3.3**).

3.2.3 Acquisition of JIS Certification

Furthermore, Kimitsu Works has previously acquired JIS Certification of a blast furnace slag aggregate (**Table 3.1**) (Authentication No.TC 03 07 338) and is supplying high quality products that customers can use safely based on the high quality control that covers the integrated processes from production to shipment together with incessantly continued improvement activities.

3.3 Examples of application of soft ground improvement technology

3.3.1 Examples in land area

In residential development, road construction, and maintenance work, there is sometimes a need to improve soil to enhance the strength of the ground because of the ground being soft. A steelmaking slag contains a moderate content of lime; thus, a hydrated solidified material formed by mixing the steelmaking slag and soil can be expected. Accordingly, excellent performance as a soft-ground-improving agent can be exercised by studying the particle size and mixing ratio of a steelmaking slag corresponding to the particle size and water content characteristics of the soil at site.[6] **Figures 3.4** and **3.5** show examples of ground improvement wherein a soft ground soil of thickness 0.5 m was mixed with a steelmaking slag on site by heavy construction machinery, and after being improved, the process was completed with the banking of soil to about 1.5 m height.

3.3.2 Examples in marine area

When compared with other soils, Dredged soil generated routinely by the work for securing courses has been used for backfilling a deeply excavated part in a sea bed; however, the construction of seaweed forest becomes possible on coastal waters, where sunlight tends to be insufficient to develop the forest; by constructing a shallow bottom, using the soil (CaO-improved soil) which is made of a mixture of dredged soil and steelmaking slag, having adjusted particle sizes and compositions and thereby having strength improved by exploiting the steelmaking slag solidification behavior and, by simultaneously installing artificial stone material made of a steel slag hydrated matrix body (Vivary™ rock) (**Fig. 3.6**).[8, 9)]

Practically, construction was performed on the waters near Kimitsu Works, and improvement in dredged soil strength, improvement in water environment in stagnant pool such as in a basin, and growth of fishes and seaweeds in the shallow bottom and the seaweed bed were confirmed.

Thus, in the improvement of soft soil, whether in land or marine area, subject construction site is huge, even if a mixing test of soft soil and steelmaking slag is conducted in advance and even if the basic mixing ratio that enables the emergence of the required strength is predetermined, sometimes the required strength is difficult to be achieved depending on the properties of soft soil. Even under such a situation, an on-site mixing ratio alteration test refer-

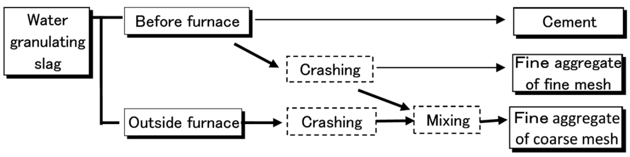


Fig. 3.3 Production flow of blast furnace slag fine aggregate

Table 3.1 JIS blast furnace slag aggregate of the Kimitsu Works

Product line	Product name
Blast furnace slag coarse aggregate	BFG20-5 N
Blast furnace slag fine aggregate	BFG20-5 L
Blast furnace slag fine aggregate	BFS5-0.3

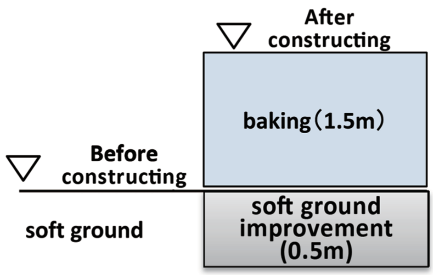


Fig. 3.4 Cross section of the soft ground improvement

Fig. 3.5 Construction situation of the soft ground improvement

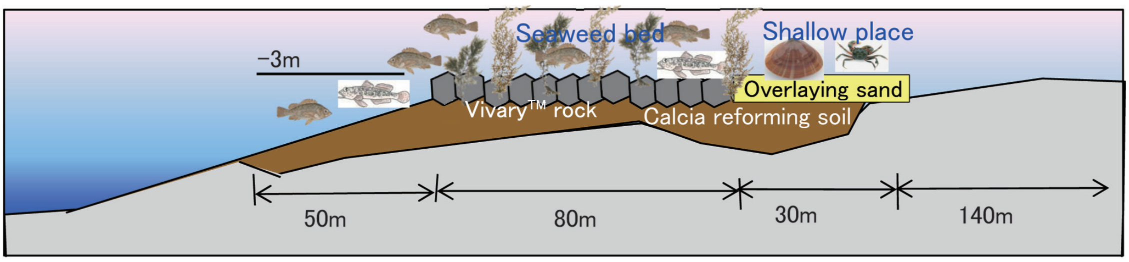


Fig. 3.6 Construction of the seaweed bed and shallow place with the Calcia reforming soil

ring to a foregoing test result and an investigation of strength are performed, and by conducting an adjustment of mixing as necessary, securing the required strength is realized.

3.4 Conclusion

Kimitsu Works will continue to make efforts hereafter to pay utmost attention to the environment to satisfy broad social needs and to continue the production and supply of reliable and safe slag products.

To add, 3.2.2 is a part of the result of the joint research and development performed with Messrs. Taiheiyo Cement Corporation, and 3.3.2 is an example realized under the support of Messrs. Land Development Department of Chiba prefecture, Messrs. Agriculture, Forestry and Fisheries Department of Chiba Prefecture, Messrs. Chiba Ports Office of Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Messrs. Federation of Fishery Cooperative Association of Chiba Prefecture, Messrs. JFE Steel, "Study Group on Water Environment" wherein Nippon Steel and Sumitomo Metal is a member, and Messrs. Kimitsu City of Chiba Prefecture. To these organizations, authors wish to express utmost gratitude by taking advantage of this opportunity.

4. ORP Slag Fertilizer Development at Nagoya Works

4.1 Introduction

A conventional major slag fertilizer for the agricultural industry was the blast furnace-slag-based "Keikaru" and steelmaking-slag-based "Minekaru." On the other hand, at Nagoya Works, a converter-type molten iron pretreatment process (LD-ORP) started its operation in 1989, and since then, the rate of molten iron pretreatment has rapidly increased; therefore, a technical study on the applicability of a molten iron pretreatment slag to a fertilizer has been promoted. Technical staff of the steelmaking plant at that time conducted technical research on the feasibility of the commercialization of a molten iron pretreatment slag as a silicate fertilizer, and then, the fertilizer that is commercially termed as "NOURYOKU-UP" was developed as an original product of Nagoya Works.

4.2 Points in developing slag fertilizer

Generally, three major well-known elements are required in a fertilizer: nitrogen, phosphorus, and potassium. In addition, in the field of the study of agriculture, research on the manuring effect of respective components has progressed and various effects of soluble silicic acid, water-soluble silicic acid, soluble magnesia, alkaline (oxidized calcium), iron content, manganese, and so on have been clarified (**Table 4.1**).

Fertilizer merchandise of Nagoya Works at that time consisted of "Keikaru," which is made of a blast furnace slag, and "Minekaru," which is made of a steelmaking slag. On the other hand, because a molten iron pretreatment (ORP) slag is produced in a steelmaking refining process for molten iron, the slag is equipped with the characteristics of both a blast furnace slag and a steelmaking slag; therefore, the slag contains silicic acid, lime, phosphorous acid, iron, manganese, and magnesium in a well-balanced manner. Thus, research was conducted expecting that the developed fertilizer, as a multifunctional fertilizer, will realize the reduction of load owing to a reduction in spraying amount per unit area.

4.2.1 Supply of silicate ions

In rice farming, the vital part of agriculture, Gramineae belongs to silicicolous plant, and its roots, stalks, and seeds contain silicic acid of a high concentration; therefore, how to supply silicic acid efficiently to paddy rice roots is an important point.

Generally, ionization in a solution of an oxidized material at room temperature tends to advance more easily under an acidic condition. Therefore, the degree of the ionization of "soluble silicic acid" in hydrochloric acid of pH = 0.7 is determined using an official analytical method of measuring fertilizer elements. On the other hand, the degree of the ionization of "water-soluble silicic acid" in ion-exchanged water of pH = 6–7 is determined using a nonofficial method for assessing manuring effects.

The reason for determining the degree of ionization in hydrochloric acid is to grasp the entire concentration of silicic acid that the fertilizer contains, and the reason for measuring it in ion-exchanged water is to grasp the concentration of silicic acid eluted under the condition close to that of a paddy field.

There are two types of silicate fertilizer products of a slag: Keikaru, which is made of a raw material of a blast furnace slag, and Minekaru, which is made of a raw material of a steelmaking slag. At pH = 0.7, a blast furnace slag exhibits higher values of silicic acid elution. On the other hand, at pH = 6–7, where paddy rice actually grows, a trial sample made of an ORP slag as a raw material exhibited higher values of silicic acid elution (**Fig. 4.1**), and harvest improvement was confirmed in the rice field test (**Fig. 4.2**).

Table 4.1 Feature of elements and the contents of various manure ingredients

Elements	Feature	Kei-Karu (BF)	Mine-karu (BOF)	Test (ORP)
SiO_2	Resistance for the lodging of the paddy-rice, restraint of the pest	31	10 - 13	23
CaO	Neutralization of the acid soil	40	35 - 40	43
Fe_2O_3	Neutralization of the acid soil	–	20 - 25	10
MgO	Ingredient of the chlorophyl	5	3	1.6
P_2O_5	Breathing action before the photosynthetic and glycolysis	–	1	2.5
MnO	For various oxidation-reduction enzymes, generation of the chlorophyl	–	2 - 4	7

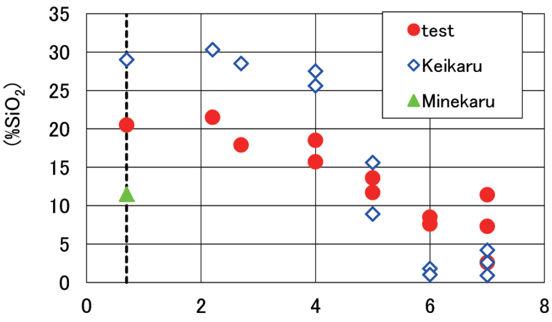


Fig. 4.1　Silicic acid elution test result

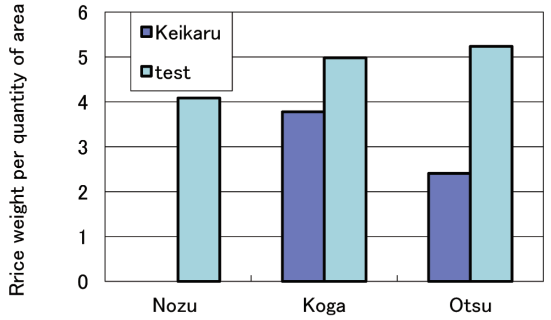


Fig. 4.2　Result of rice field test (Shiga Pref.)

4.2.2 Prevention of autumn decline

There is a phenomenon termed as autumn decline, which means that the growth of paddy rice decays in the season of ear emergence and the amount of harvest drops. It is said to be caused by paddy rice roots being damaged by hydrogen sulfide generated in a soil. Such a decay is considered to be attributed to Japanese soil being originally acidic and allegedly to a decreasing pH of rainwater on the coastal area of the Sea of Japan due to increase in PM to 2.5 in recent years. As countermeasures, it is said that the use of a fertilizer that supplies iron and manganese to produce sulfide stably under a natural condition is effective. As understood from Table 4.1, a test sample contains iron and manganese more than conventional Keikaru, and the sample (fertilizer made of Nagoya-ORP slag) has grown to be the merchandise excellent in performance.

4.3 Implementation of plant tours

At Nagoya Works, under the cooperation of the National Federation of Agricultural Cooperative Association and respective agricultural cooperative associations, plant tours for agricultural households all over Japan are implemented throughout a year, and we have the pleasure of inviting 100–200 guests to the steelworks annually and make a tour to blast furnace plant, steelmaking plant, and fertilizer plant; through meetings for an exchange of opinion, we can have the opportunity of hearing customers' requests regarding a fertilizer, and such requests are considered in production and sales (**Photo 4.1**).

As a result, a farming household user of “NOURYOKU-UP™” was awarded the golden award in an international rice concur (2012 Fy), and fruitfulness is growing steadily (**Photo 4.2**).

In recent years, what is discussed in a plant visit is a jump in the price of phosphate rock. What lies behind the international food issue is the growth of demand for a fertilizer in East Asian countries, including China. On the other hand, steel slag including a merchandise is produced as a result of removing and condensing phosphorus present in blast furnace molten iron. It is considered that helped by a recent increase in phosphorus concentration in iron ore, phosphoric acid concentration in a steel slag will increase more hereafter and the slag will become a valuable supply source of phosphorus for Japan, which has scarce resources.

Photo 4.1　Steelworks plant tour

Photo 4.2　Golden award of Rice Concur

4.4 Current status of shipment of NOURYOKU-UP

Shipment of the silicic acid fertilizer made of a material of a molten iron pretreatment slag in the steelworks was started in 2000 under the commercial brand name of “NOURYOKU-UP” by the Sangyo Shinko Co., Ltd. after the company's development of granulation technology for commercialization as a fertilizer product following the development of samples in 1998. Thereafter, the amount of sales has continued to grow steadily, and currently, it exceeds 20 thousand tons on annual base.

4.5 Conclusion

Owing to the neutrality of pH = 6–7 and the compositions that allow an easy elution of silicic acid ions, the fertilizer using a molten iron pretreatment slag from Nagoya Works provides a high manuring effect even with spraying in a small quantity; because the fertilizer contains both compositions of blast furnace slag and steel slag (iron content, manganese in particular) compounded in a well-balanced manner, it has been proved that the fertilizer has a high manuring effect even when sprayed solely in a small quantity. Furthermore, steelworks is contributing to farming households' improvement in profitability through an improvement of quality realized via a plant tour and to society by responding to overseas study tours.

Acknowledgement

For numerous advices given to us for about 17 years in the past since the start of the development up to the present, authors would like to express utmost gratitude to the concerned Members of the Tokyo University of Agriculture, headed by Professor Goto, respective Farming Households, National Federation of Agricultural Cooperative Association and respective Agricultural Cooperative Associations, and Fertilizer Business Division and Nagoya Plant of the Sangyo Shinko Co., Ltd.

5. Current Status of Development at Wakayama Works

5.1 Blast furnace slag

5.1.1 Concrete aggregate use

The share of a blast furnace slag concrete aggregate is about 25% at Wakayama Works, and the amount of shipment reached about 330 thousand tons in fiscal 2012 (**Table 5.1**). The product mix is shown in **Fig. 5.1**. About 120 thousand tons of a blast furnace slag fine aggregate is produced annually in the off-furnace-site water-granulation equipment (commissioned in 2005) and sold. Furthermore, about 160 thousand tons of a blast furnace coarse slag aggregate (5–20 mm) is produced annually by air cooling, crushing, and classifying at a slag treatment shop and sold.

A blast furnace slag below 5 mm in particle size, which is generated during the production of a blast furnace coarse slag aggregate (5–20 mm), is further classified to 2.5 mm–5 mm and to below 2.5 mm in size by a wet-type classifying equipment [10] (commissioned in 2010), and about 50 thousand tons is produced and sold annually for an aggregate material use of concrete secondary products.

Table 5.1 Product mix of concrete aggregate in blast furnace slag

Item	Production (kilo ton/2012Fy)	Remarks
Fine aggregate for concrete	118	Offline water granulation equipment
Coarse aggregate for concrete (5-20 mm)	160	Air cooling in yard
Concrete product aggregate (2.5-5 mm)	26	Wet classification equipment
Concrete product aggregate (under 2.5 mm)	25	Wet classification equipment
Total	329	

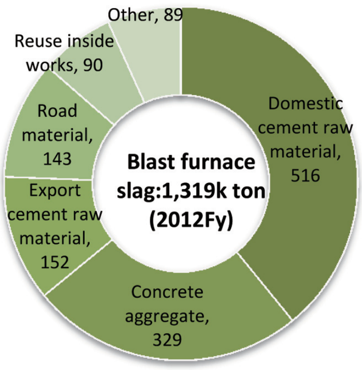


Fig. 5.1 Product mix of blast furnace slag

The content of commercialization for concrete secondary products was evaluated and was awarded the encouragement prize in fiscal 2012 for resource recirculating technologies and systems.[10]

Concrete secondary products have been registered in NETIS (New Technology Information System) of the Ministry of Land, Infrastructure, Transport and Tourism as “Concrete secondary products 100% made up of air cooled blast furnace slag aggregate” (Registration No: KK-11041-A).[11]

5.2 Steelmaking slag

5.2.1 Reuse rate of material used in steelworks

At Wakayama Works, the reuse of a sintering material of a desulfurizing slag produced in a desulfurizing process of a steelmaking process has been tackled; however, the slag produced was not effectively used to the point of balancing between the amounts of production/consumption, constrained by the allowable amount of the discharge of SO_x in the exhaust gas. To satisfy the commissioning of the new No.1 blast furnace started in 2009 and as a part of reinforcing No.5 sinter plant, desulfurization and denitrification equipment started operation in 2008, and as a result, the reuse of the entire desulfurizing slag produced became possible, and the reuse rate of a steelmaking slag as a material used in steelworks could be drastically increased. Furthermore, by controlling the particle size of the slag, a reduction in RDI (index of disintegration during reduction) and in the unit consumption of a coagulation material was confirmed; moreover, the use of the slag in a greater quantity has become possible, and the reuse rate has reached about 50% (**Fig. 5.2**).

5.2.2 Concrete pavement using steelmaking slag [12]

Development of a concrete pavement using a steelmaking slag as an aggregate is under study. In the pavement construction work in the steelworks, lower initial cost and start of use within a short period of time are required in view of its relation with cost and operation, and to solve these issues, a laboratory test was performed to determine the applicability of a steelmaking slag aggregate to “1 DAY PAVE” developed by the Technical Committee for Pavement of Japan Cement Association. Moreover, a test construction was performed on the premise of Wakayama Works. The results of the tests showed no problems in production, shipment, and transportation. The slump flow value was 41.5 cm, and the air content was 4.4% on arrival at site; both satisfied the aimed values (**Table 5.2**).

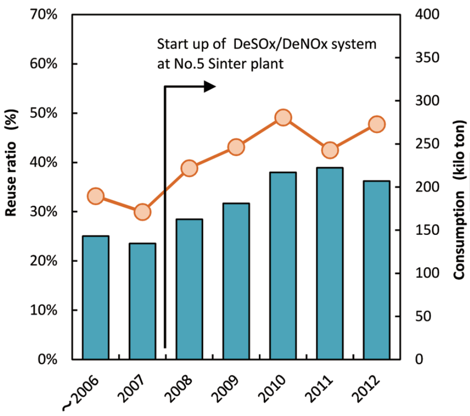


Fig. 5.2 Reuse ratio and consumption of steel making slag

Photo 5.1 Placing of concrete

Table 5.2 Result of quality control test

Slump flow (cm)		Air content (%)	
Before delivery	At construction site	Before delivery	At construction site
40.5	41.5	3.5	4.4

Photo 5.2 Pavement surface after hardening

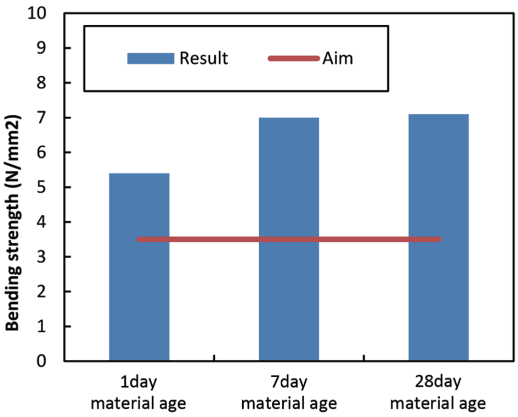


Fig. 5.3 Result of bending strength

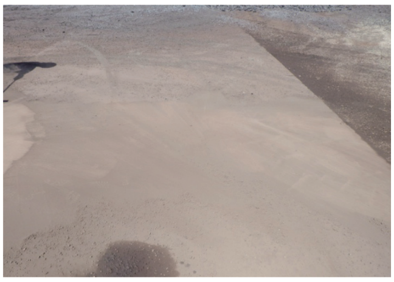


Photo 5.3 Pavement surface a year later

Furthermore, bending strength at one day material age was 5.40 N/mm^2, satisfying the aimed value (**Fig. 5.3**). In addition, workability was basically good, and no plastic shrinkage cracks developed right after pouring; moreover, no cracks developed by drying contraction were observed (**Photos 5.1**, **5.2**).

In a visual inspection performed after one year, no shrinkage cracks and other problems were found. The observation of changes over years and expansion of the area of application will be attempted hereafter (**Photo 5.3**).

6. Production and Usage Technology Developments of Ash Stone at Hirohata Works

6.1 Introduction

The importance of coal is reevaluated as an alternate energy resource of petroleum, and the construction of coal-fired thermal power plants is in progress in many places. With the commissioning of such coal-fired thermal power plants, a great volume of coal ash will be generated. A major usage of coal ash is as a cement material; however, there is a limit in such a usage, and therefore, the determination of new usages is being sought for.

The Hyogo prefectural study group for slag road base course materials (Kobe University, Hyogo Prefecture, Kobe City, Nippon Slag Association) conducted a study on a supplementary material of a road base course made of granulated/lumped coal ash (name: ash stone) to promote the utilization of coal ash. This study introduces the outline of how the development of ash stone has been tackled and how it is used.

6.2 History of development of ash stone

The use of coal ash mixed with existing road base course materials in the form of a powder was approved in the past in Hyogo Prefecture. However, because it was used in a powder form, consumable amount was very small (about 2%–7%) and dispersing was a problem. To solve these problems, the development of ash stone by lumping coal ash was performed.

6.3 Test construction using ash stone

Aiming at the realization of the practical use of ash stone, the Hyogo prefectural study group for slag road base course materials conducted two tests on actual prefectural roads using a hydraulic mechanically stabilized slag (hereafter called as HMS-25) mixed with ash stone. Both constructions were performed in 1999, and an investigation of paving performance such as cracks on road surfaces, surface roughness, and maintenance index was performed for three years. Then, it was confirmed that the materials have the performance equivalent to existing road base course materials, and the use of the materials was approved by Hyogo Prefecture.

Introduced below is the result of one of the tests performed on the Kobe/Akashi line of Hyogo prefectural road (Akashi City in Hyogo Prefecture, length: 132 m). **Figure 6.1** shows a sectional view of the test construction. **Table 6.1** shows the quality test result of the used material, and **Table 6.2** and **Figs. 6.2–6.5** show the results of follow-up surveys. This result of investigation was reported at the research meeting of the Hyogo prefectural study group for slag road base course materials in March 2002.[13)]

6.4 Production of ash stone

Hiroko-Giken Co., Ltd. (now Nippon Steel & Sumikin Slag Products Co., Ltd., Hirohata Office) started a commercial operation of an ash stone manufacturing plant in September 2003, right after ash stone was approved by Hyogo Prefecture. Hiroko-Giken used the ash generated in a fluidized-bed boiler at Hirohata Works of Nippon Steel & Sumitomo Metal (hereafter called as Hirohata).

Generally, fluidized-bed boiler ash contains rich CaO and SO_3 and has properties of becoming lump at the addition of water. Using this fluidized-bed ash, a reduction in the amount of the addition of cement became possible. Furthermore, using a special equipment (a mixer) for mixing, kneading, and granulating, processing in one stage instead of processing in three stages has become possible by a single manufacturing equipment. The sketch of the manufacturing equipment is shown in **Fig. 6.6**.

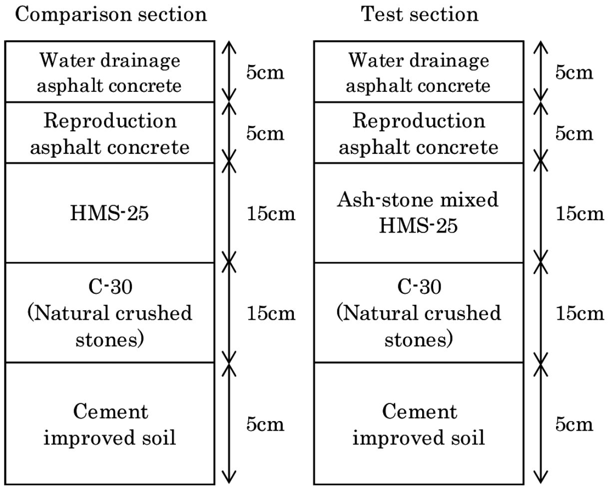


Fig. 6.1 Test sectional view

Table 6.1 Quality test result

	HMS-25	Ash-stone mixed HMS-25	Standard
Unit capacity mass (N/m³)	19.3	18.1	≧ 15.0
Correction CBR * (%)	175	170	≧ 80
Compressive strength (N/mm²)	1.55	1.71	≧ 1.2

* CBR : California Bearing Ratio

Table 6.2 Results of follow-up surveys

Section	Assorted traits	Directly		6 months		12 months		18 months		24 months		30 months		36 months	
		Up line	Down line	Up line	Down line	Up line	Down line	Up line	Down line	Up line	Down line	Up line	Down line	Up line	Down line
Comparison section	Crack rate (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Amount of average tracks (mm)	13.2	8.6	14.5	12.8	16.5	14.5	16.4	14.7	16.3	15.1	16.7	15.4	16.6	16.5
	Flat nature (mm)	2.0	1.8	1.8	2.8	2.9	3.0	3.2	4.9	4.9	3.8	3.2	4.9	3.2	4.9
	MCI *	7.7	8.2	7.6	7.7	7.4	7.5	7.4	7.5	7.3	7.4	7.3	7.4	7.3	7.3
Test section	Crack rate (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Amount of average tracks (mm)	12.4	11.0	14.4	13.6	16.1	16.2	16.1	16.2	16.5	16.7	16.2	16.8	16.2	16.9
	Flat nature (mm)	1.7	1.7	2.5	2.7	2.6	2.7	3.9	3.5	3.5	2.6	4.0	3.6	4.0	3.7
	MCI *	7.8	8.0	7.6	7.7	7.5	7.4	7.5	7.4	7.5	7.5	7.5	7.4	7.4	7.3

* MCI : Maintenance Control Index

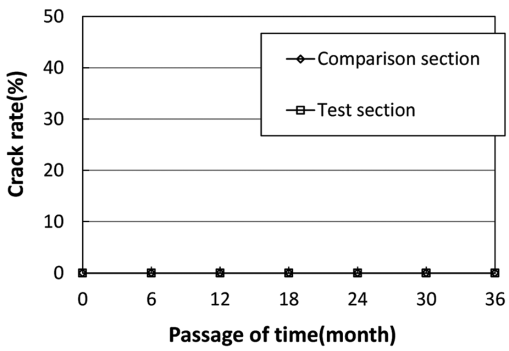


Fig. 6.2 Results of follow-up surveys (crack rate)

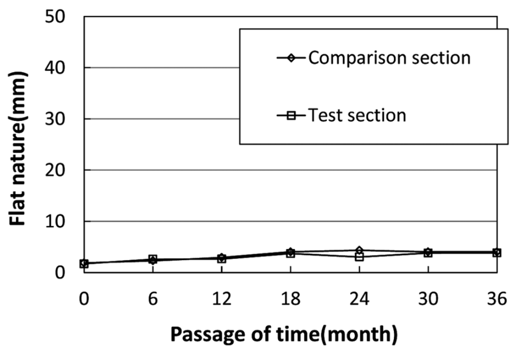


Fig. 6.4 Results of follow-up surveys (flat nature)

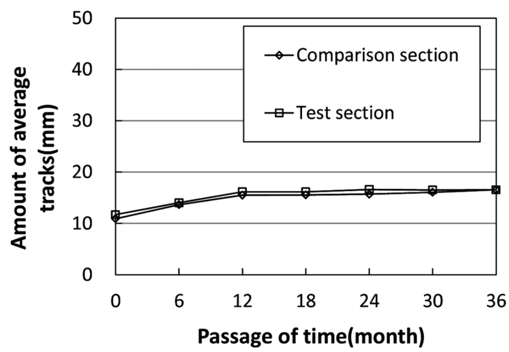


Fig. 6.3 Results of follow-up surveys (amount of average tracks)

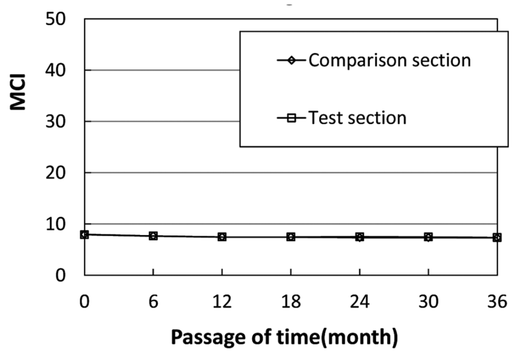


Fig. 6.5 Results of follow-up surveys (MCI)

Since the start of a commercial operation of the ash stone manufacturing plant, Hiroko-Giken productizes almost an entire amount of the fluidized-bed ash generated in Hirohata.

6.5 Conclusion

As introduced above, since the start of a commercial operation of the ash stone manufacturing plant, Hiroko-Giken has productized the fluidized-bed boiler ash generated in Hirohata and continues to sell a road base course material mixed with the material specifically to public works in Hyogo Prefecture. We will try for a quality improvement and marketing effects more in future.

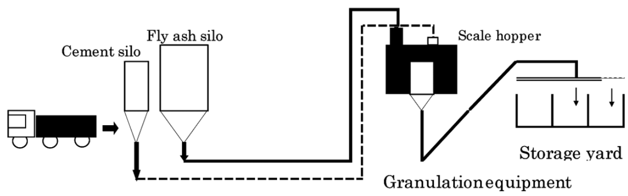


Fig. 6.6 Equipment key map of production equipment

Acknowledgement

By taking advantage of this opportunity, authors would like to express utmost gratitude to the member organizations of the Hyogo prefectural study group for slag road base course materials for their great support extended in writing this paper.

7. Slag Usage Development at Yawata Works

7.1 Introduction

On April 1st 2014, the former Yawata Works and the former Kokura Works were integrated to the new “Yawata Works” and the Yawata Works started its operation. This study describes the current status of iron and steelmaking slag usages at former Yawata Works.

7.2 Utilization of blast furnace slag

7.2.1 Start of iron and steelmaking slag uses [14, 15]

In Tobata district of Yawata Works, Tobata No.4 Blast Furnace is in operation currently. A blast furnace slag is produced in a blast furnace. A produced water granulated slag is used as cement material, aggregate, and material used in civil engineering works, and an air cooled slag is used as a road base course material.

Application of a water granulated slag to cement has a history of approximately one century, which has its origin in the test and research for producing cement from a blast furnace slag, conducted in 1910 after the start of Higashida No.1 Blast Furnace at the former Yawata Works in 1901. Later in 1913, a Portland blast furnace slag cement plant, the first one in Japan, was constructed in Maeda district, and currently, production is performed by Nippon Steel & Sumikin Cement Co., Ltd. (in Kokura district). As a part of such a history, this study summarizes how iron and steelmaking slags are used and how they have been developed mainly since 2000.

7.2.2 Effective utilization of blast furnace slag

7.2.2.1 Use of blast furnace slag with soil excavated at site [16]

One of the water-shielding methods for the construction of a waste dump site is the employment of a structure of a combination of a clay layer and a water-shielding sheet. As a water-permeability coefficient of less than 10^{-7} cm/s is required for water-shielding materials, water-shielding performance is improved conventionally by mixing soil excavated at site with bentonite. On the other hand, to relieve load on the sheet by the influence of the deformation of ground developed by the weight of waste, securing strength to a certain degree is needed. Thus, water-shielding material composed of soil excavated at site and bentonite mixed with ground granulated blast furnace slag has been developed.

In 2001, this system was employed in the construction of a general waste disposal site projected for a reclamation area of 5000 m^2 and reclamation volume of 12000 m^3 in Asahi Town, Kamikawa Gun in Hokkaido.

7.2.2.2 Use of granulated blast furnace slag in civil engineering works [17]

On the Kyushu Shinkansen Line, which was partially put into public service in March 2004, there are numerous tunnel structures that pass through the ground composed of shirasu that specifically exists in Kyushu (white pumiceous soil of southern Kyushu), where a water-permeable road base course material using a granulated blast furnace slag is used. The function of the water-permeable road base course material is to reduce the level of underground water around the tunnel and prevent the mad pumping in shirasu ground. In many tunnels constructed through mountains composed of shirasu, an invert structure constructed with concrete has been employed usually in the past; however, shirasu has a poor resistance to water, and thus, a repeated train load that is supported by the resistance to water has caused a problem.

A granulated blast furnace slag is a sand-like granular material, and because it has water permeability and supporting force required for a road base course material, it is now employed for a railroad base course material.

In March 2011, the entire Kyushu Shinkansen Line was put into public service, currently functioning as the main artery connecting Kyushu and Honshu.

7.2.2.3 Development of blast furnace slag with molten fly ash [18, 19]

Needs of using a blast furnace slag as a concrete aggregate are growing because of recent restrains on the gathering of sea sand, exhaustion of natural aggregates, and so on. Yawata Works sells granulated blast furnace slags as fine aggregates, and as a new attempt, it has developed a blast furnace slag with molten fly ash, wherein fly ash is added to a molten blast furnace slag. Much of fly ash is used as a raw material for cement; however, its effective utilization is not advanced well because of a problem of unburnt carbon.

Then, we developed a method of producing a concrete aggregate by injecting fly ash into a molten blast furnace slag and melting the fly ash in a ladle. The blast furnace slag with a molten fly ash fine aggregate satisfies the standard values of JIS A 5011. In a mortar test in which the entire amount of the aggregate was used, a blast furnace slag with a molten fly ash fine aggregate containing fly ash of 10% at maximum showed performance not inferior to that of a mortar using sea sand. We will continue its study as a method to solve the problem in fly ash disposal.

7.3 Utilization of steelmaking slag

In iron and steelmaking slags, the use of a steelmaking slag has become fully dressed after JIS for iron and steelmaking slags for a road base course was established in 1979. Later on, primarily for use as a road base course material, a new compound road base course material mixed with recycled concrete has been developed. Furthermore, technologies using a steelmaking slag as a material for improving soft ground have been developed. A steelmaking slag is currently attracting attention as a harbor construction material. In this study, the development of the new compound road base course material and the development of the application of a steelmaking slag to harbor construction materials are described.

7.3.1 Development of new compound subbase material [20]

As for iron and steelmaking slag road base course materials, hydraulic and mechanically stabilized slags mainly composed of a blast furnace slag (HMS) are used as upper-layer road base course materials; however, because a steelmaking slag has characteristics such as low hydraulicity and small uniaxial compressive strength, it cannot be used as an upper-layer road base course material. On the other hand, the recycled concrete made of waste concrete generated during disassembling a concrete structure cannot be used by itself as an upper-layer road base course material because of problems such as varying strength. Then, a new compound road base course material was developed by combining iron and steelmaking slags with the recycled concrete.

The merits of the combination are as follows:

- Utilization of re-hardening characteristics of an unreacted cement component existing in a recycled concrete material
- Early emergence of the latent hydraulic property promoted by the alkalinity of the recycled concrete
- Stabilization of physical properties by mixing with iron and steelmaking slags

As a result, the new compound road base course material having mixing ratios of 45% of recycled concrete, 30% of steelmaking slag, and 25% of blast furnace slag and having the properties equivalent to those of conventional HMS25 has been developed and is currently used as a material in civil engineering works in Kitakyushu City.

7.3.2 Use of iron and steelmaking slag in marine area

7.3.2.1 Materials for improving marine conditions

As materials for improving marine conditions, Nippon Steel & Sumitomo Metal has developed products for developing fishing grounds and seaweed beds such as Vivary™ series [21] in which an iron-content-bearing steelmaking slag and artificially developed humus soil are mixed. The effort made in Mashike Cho in Hokkaido is a typical example of these products.[22] In Kyushu, numerous phenomena of sea desertification are observed, especially in the northern region of Kyushu. As an example, in a marine forest restoration project in Ishida district of Iki City in Nagasaki Prefecture, the thick growth of seaweed such as Eisenia around Vivary™ series products has been confirmed after three years since they were installed in 2010.[23] The city also installed Vivary™ series products in another area, and further employment as materials for improving the marine environment is intended hereafter.

7.3.2.2 Study on method of improving dredged soil

In recent years, disposal sites of dredged soil generated by waterway dredging works are being filled up, and their effective use is being sought for. In 2008, a manual for improving dredged soil using a steelmaking slag [24] was issued by Japan Iron and Steel Federation. At Yawata Works, a test on soil-improving work using CaO-improved soil was conducted for the dredged soil generated in dredging work to secure the emergence of strength needed for use as ground when it is disposed in a landfill disposal site.[25]

After unloading, dredged soil was dumped into a pit, and then, a steelmaking slag was also dumped into the pit; subsequently, they were mixed and stirred by a backhoe. For application, the aimed strength of CaO-improved soil was set at above the cone index of qc = 200 kN/m^2 and the mixing ratio of the slag was set at 30% so that qc = 400 kN/m^2 could be obtained because the safety coefficient of site-controlled strength was set at 2. Furthermore, as an index for site quality control, the extent of mixing is estimated by on-site weight per unit volume based on the interrelation between backhoe mixing time and on-site quality. When similar works occur hereafter, the employment of CaO-improving method as means of the effective utilization of iron and steelmaking slag and reduction in cost are intended.

7.3.2.3 Study on Steel Slag Hydrated Matrix containing dredged soil [26]

The effective utilization of dredged soil has become a subject in various places in Kyushu. In the Hakata Bay, dredging works are in progress to secure the depth of waterway, and as a part of the effective utilization of the gathered dredged soil, a steel slag hydrated matrix containing dredged soil was produced by mixing dredged soil, steelmaking slag, and ground granulated blast furnace slag. The production process is as follows: dredged soil, steelmaking slag, and ground granulated blast furnace slag are premixed on site, and a total amount of 30 m^3 was kneaded and then poured to molds; after curing, they were crushed to pieces of weight 300–500 kg per piece. After confirming the 28-day strength, a steel slag hydrated matrix containing dredged soil was dumped at the site marine area to be used as fish reef and seaweed bed stone. The required strength of solidified dredged soil body was set at approximately above $\sigma_{28} = 10$ kN/mm^2, and by measuring the wet density at site, the ratio of the mixture was re-examined. Based on the series of these works, a method of producing fish reef and seaweed bed by mixing dredged soil on site has been established.

7.4 Activities for assessing iron and steelmaking slags as environmental materials [20]

The effective utilization of iron and steelmakimg slags as environmental materials is promoted, and the assessing method considering the environment and economy was studied in the Kyushu Branch of The Japanese Geotechnical Society in 2001–2002.

In this study, as a method to assess the economy and environment, model calculations of direct cost (construction material cost and construction work cost), ecology-related cost, and environmental cost were performed. The ecology-related cost is defined as "equivalent technical and practical cost incurred to eliminate environmental load generated by the production of construction material, transportation, construction of structures, maintenance/control, disassembling, and disposal." Furthermore, in the specific model calculation, the amount of the emission of the life cycle carbon dioxide ($LCCO_2$) is used as an index. The model calculation of the $LCCO_2$ was performed as to the amount of carbon dioxide emitted by the gathering of materials for construction works, production, transportation, and heavy construction machinery in construction works, wherein for an iron and steelmaking slag, the saving of disposal by reclamation and the avoidance of disposal using an iron and steelmaking slag as effective materials were calculated and incorporated into the model calculation and assessed. Furthermore, the environmental cost is sought for as relative environmental cost incurred to construction materials, which is calculated based on the benefit transfer method that assesses the influence of used materials on forest ecology system, deterioration in residential environment, drop in land price, and so on.

In the study, a comparison of cost is conducted between the case of using an iron and steelmaking slag and of using a natural material (riprap and sea sand) in a model design of a harbor construction work. The model design was performed for the case of a quay wall structure (caisson type) of 100 m in length and −7.5 m in depth of water. The merits of using an iron and steelmaking slag are as follows:

- Earth pressure is relieved using a granulated blast furnace slag as a back-filling material.
- Resisting moment to earth pressure is increased using a steelmaking slag as a caisson-filling material.
- Steelmaking slag as a material of SCP (sand compaction pile method of construction) has a large angle of internal friction and resistance to circular slipping; therefore, the range of improvement is made smaller.

As a result of the model calculation, for the entire construction work, a reduction of 9% in the direct cost as compared to the case of using a natural material has been realized. Furthermore, although the rate of reduction in the ecology-related cost is 4% in case only construction is solely concerned, it is considered that when the result of the effective use of an iron and steelmaking slag as a recycled material is incorporated, the effect of a reduction of about 30% can be expected in case the entire construction work is concerned.

The model calculation of the environmental cost shows that the load to the environment can be suppressed to about one forth in case an iron and steelmaking slag is used instead of a natural material. It is reported that based on these results, effects in reductions in direct cost, ecology-related cost, and environmental cost are expected by the effective utilization of an iron and steelmaking slag.

7.5 Conclusion

One century has passed since the beginning of the use of iron and steelmaking slags. For the future generations, authors would like to supply iron and steelmaking products satisfying a change in social environment and needs brought forth and contribute to regional development.

8. Iron and Steelmaking Slag Usage Developments at Oita Works

8.1 Introduction

Oita Prefecture is situated in a temperate region of the Seto Inland Sea and has prosperous primary industries such as marine products industry, agricultural industry, and forestry industry by taking advantage of its natural resources and environment such as the Bungo Strait with rich marine resources and village-vicinity mountains that stretch from Kuju mountains that lie behind.

Oita Works, situated at a location in the said region, is the last constructed latest integrated steelworks in Japan, and for about 43 years, it has continued production operation integrated with activities of regional communities.

Recently, the steelworks is promoting the utilization of slag products produced at Oita Works in several agricultural and fishery-related subjects in administrative and private sectors, thereby promoting contribution to regional communities. Such examples are explained below.

8.2 Contribution to agriculture

8.2.1 Development of special fertilizer (GANTETSU HIRYO)

It is needless to state that a steel slag contains elements such as iron, boron, and manganese, which are indispensable to the growth of a vegetable as a mineral ingredient in addition to the basic manuring ingredients such as lime, silica, and phosphoric acid, in extremely small quantities. Oita Works conducted sales of a steelmaking slag primarily as a fertilizer; however, in recent years, the amount of sales of fertilizers has dropped because of the influence of a recent national policy of reducing acreage, and thus, steelworks interrupted the iron and steelmaking slag fertilizers in 2002.

In particular, for a steelmaking slag to be used as a lime fertilizer, because the elution rate of lime is low and the fertilizer is slow-acting in nature, the manuring of a lime fertilizer more than ten and several times of the required amount becomes necessary. Even if its effect lasts for ten and several years, it is not an easy job to manure several tons of fertilizers per 10 ares at once; therefore, the fertilizer is not appropriate for small-scale farmers who do not own heavy machinery or for vegetable farmers in mountainous areas with narrow approach roads. Such inappropriateness was the major cause of poor sales of the fertilizer.

However, Oita Works changed its viewpoints in 2007. For specifically large-scale farmers who have large-sized heavy machinery, the development of a steelmaking slag fertilizer was restarted on the basis of sales that transport and deliver merchandise with a delivery lot of a truckful load of 10 ton to suppress transportation cost. As shown in **Photo 8.1**, a special fertilizer named “GANTETSU HIRYO (iron-bearing fertilizer)” using a steelmaking slag was developed.

Authors conducted a joint test with Hohi Development Bureaus of Oita Prefecture, which places emphasis on the support of agriculture, Safe Agriculture Research Institute of the prefecture, and a large-scale farmer in Taketa City, and 22 tons/10 ares in a block was manured (**Photo 8.2**). Since years before, a steelmaking slag fertilizer is said to have a protective effect on plant disease such as clubroot that infects a leaf vegetable of Brassicaceae,[27] and it was proved that this product has the same effect. Furthermore, it has the manuring effect that enhances the growth rate of vegetables (Refer to **Fig. 8.1, Photos 8.3**, **8.4**).

Later in 2009, the steelmaking slag fertilizer was named “GANTETSU HIRYO” and registered to Oita Prefecture as a special fertilizer, and full-dressed sales activity was started. An example in which, in particular, the fertilizer contributed to farming ground improvement is given below.

8.2.2 Example in Sugou region in Taketa City

In Sugou region in Taketa City, where there are many large-scale highland leaf vegetable farmers, clubroot plant disease had spread in a field of 500 ha for 20 years, and they have been raising open-field vegetables using expensive agricultural chemicals. As countermeasures, in 2009, utilizing the national project of the strategic development of industries in production areas, Hohi Development Bureaus of Oita Prefecture, JA Oita, Leaf Vegetable Section of Oita Midori

Photo 8.1 Fertilizer “GANTETSU HIRYO”

Photo 8.2 Situation of fertilization

Regional Headquarters as the key members used 2000 tons of this fertilizer "GANTETSU HIRYO" in the Section members' 57 fields (23 ha) of 30 members, and test for soil improvement was conducted.[28)]

In addition to the phenomenon that the outbreak of clubroot disease was suppressed, there was another effect that a secondary crop of sweet corn showed good harvest. Sweet corn belongs to Gramineae, and therefore, the rich composition of the silica of this fertilizer is considered to have helped the growth.

8.2.3 Example in Yatsushiro City

In 2011, in Yatsushiro City, where there are many large-scale farmers of leaf vegetables, commercialization progressed under the cooperation of JA Yatsushiro; 3000 tons of the material "GANTETSU HIRYO" in the field (32.6 ha) was used and the improvement of the ground was performed.[29)]

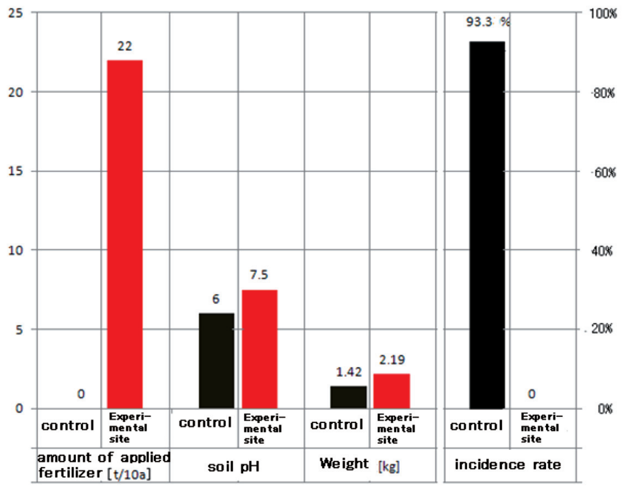
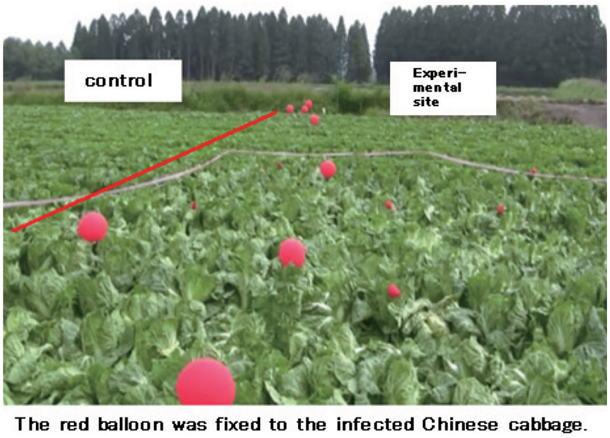


Fig. 8.1 Effect of the fertilizer on Chinese cabbage



The red balloon was fixed to the infected Chinese cabbage.

Photo 8.3 Overview of control and experimental site

Photo 8.4 Effect of the fertilizer on Chinese cabbage

However, in manuring this fertilizer of "GANTETSU HIRYO" to soil where alkalization is difficult, for instance andosol, farm ground that requires the manuring quantity of more than 10 tons/10 ares is not unusual. In this case, manuring all at once causes a problem of hardened soil. Furthermore, there is another problem of unevenly distributed nourishment; therefore, upon use of the material, your contact with Oita Works is appreciated. We accept your request for consultation, using knowhow obtained in our experience, some of which being hard to be described in written form.

8.2.4 Trial use in other regions

The tests that are being performed are as follows: (1) paddy-rice growth hastening test in Yayoi district in Saiki city using a fertilizer consisting of composted cowpat, chicken droppings, and "GANTETSU HIRYO," which is jointly conducted by Nanbu Development Bureaus of Oita Prefecture and JA Oita Saiki Division, (2) tests as countermeasures for plant clubroot of cabbage and broccoli, conducted by JA Oita Nakatsu Division, and (3) other tests for other vegetables such as spring onion, and asparagus in various regions in the prefecture have started.

8.2.5 Utilization test of insolubilizing function (improvement of Cd-contaminated field)

As for public nuisance caused by cadmium (hereafter expressed as Cd), ITAI-ITAI disease is notorious. Even at present, in some farmlands, rice containing a little bit high concentration of Cd is harvested; such farmlands are being designated by the national government as farm ground soil contaminated region, and improvement is in progress with such countermeasures as insolubilization and soil dressing. In 2011, the criterion of Cd for Japanese unpolished rice was revised to an international standard and changed from 1.0 ppm or less to stringent 0.4 ppm or less. To cope with this, although countermeasures appear ongoing, only the use of an expensive lime material and costly soil dressing appear to be available.

As countermeasures for this, under the direction of Professor Shin-ichiro Wada of Kyushu University, a test was conducted jointly with ASTEC Co., Ltd to utilize "GANTETSU HIRYO" as an insolubilizing material on a field in a certain region. The test method was; 1.6 ares, one fourth of the entire field of 6.4 ares as experimental field and adjacent 1.6 are as comparison field were used as the subject field and the fields were separated by corrugated steel sheets not to allow water flow to each other field. To control the pH of soil to about 7.5, 6 tons per 10 ares of "GANTETSU HIRYO" was sprayed in June 2009 after the harvesting of wheat, and thereafter, crop plants of rice and wheat were planted every year and continuously monitored.

As a result, as **Fig. 8.2** shows, the pH of soil increased as compared to that of the comparison field, and as **Figs. 8.3** and **8.4** show, it was confirmed that concentrations of Cd in rice and wheat harvested in the experimental field after manuring are lower than those in the comparison field, and such concentrations were maintained.

As this shows, for instance, manuring intended to increase harvest can simultaneously suppress the absorption of harmful Cd, and the effect of "Killing two birds with a stone" is obtained. It is considered that in vegetable agriculture utilizing this material of "GANTETSU HIRYO," the improvement of soil is also possible; this fact acts as a countermeasure for Cd-contaminated fields and as a preventive measure for fields, although not contaminated, in the regions

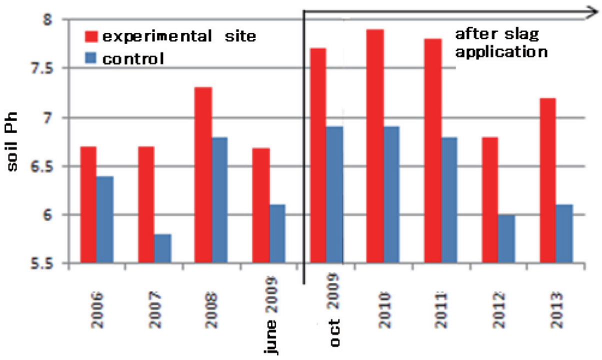


Fig. 8.2 Effect of the fertilizer on pH of soil

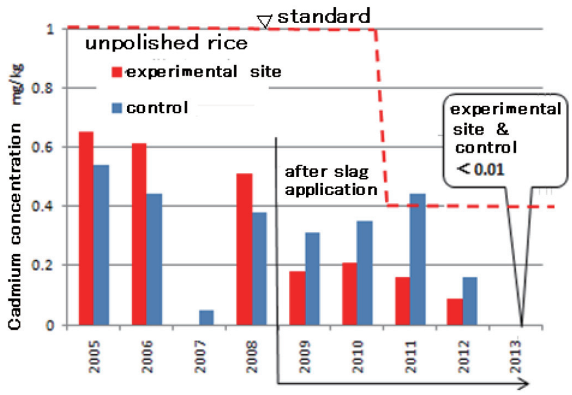


Fig. 8.3 Effect of the fertilizer on the cadmium concentration of unpolished rice

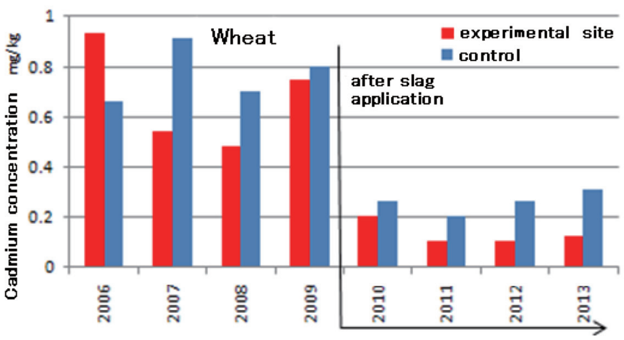


Fig. 8.4 Effect of the fertilizer on the cadmium concentration of wheat

with relatively high concentration of Cd.

8.3 Examples of application in livestock farming

8.3.1 Soil improvement for grassland

Livestock industry in Oita Prefecture represented by the one in Kuju heights is active. In this livestock industry, contribution with iron and steelmaking slag fertilizers is starting. For the livestock industry, the cultivation of grass for high harvest and high quality is important to cope with the rising livestock feed price imported from overseas. Accordingly, it is necessary to cultivate grass by utilizing fertilizer and/or soil-improving materials such as lime to neutralize the ground of high acidity.

However, the greater part of the heights in Kyushu is covered with typical volcanic soil of andosol, and acidity is high; moreover, the soil contains alumina. Therefore, alkalization is difficult. The soil is of the nature in which it is difficult for a plant to absorb phosphoric acid and the effect of a fertilizer is smaller; thus, the amount of the spray of lime and a fertilizer becomes larger, and management is suppressed.

Then, the utilization of this material as an alternate for a lime material and as a fertilizer has just started, aiming at a high harvesting of high quality grass.

However, because it is an improvement of huge meadows, influence to the environment such as underground water is concerned. Then, Oita Prefecture and Kyushu University investigated the soil when a large amount of a fertilizer was used, and the study on its influence over the environment was continued, part of which was introduced by Saeki et al, at the 2013 Autumn Regular Meeting of Kyushu Branch of Japanese Society of Soil Science and Plant Nutrition (Jointly held by Soil Science and Plant Nutrition Section of the Association of the Kyushu Agricultural Research Institution).[30] He introduced that influence on underground water was scarcely observed and phosphoric-acid-absorbing effect in plants is expected based on the result of the investigation on soil.

8.3.2 Improvement of fertilizer

Many livestock farmers make high quality fertilizers from excrement and urine generated by livestock for grass and agricultural products and implement good management. They use the "GANTETSU HIRYO" during fermentation in making a compost. For example, lime present in the "GANTETSU HIRYO" is effective in promoting the fermentation of composts and at the same time contains trace constituents that excrement and urine do not contain. Increasingly, many farmers have started using this fertilizer in their own original ways.

8.3.3 Maintenance material for maintaining pasture land

In plateau areas in Kyushu, burning fields, a spring common feature, starts in February. It is needless to state that this burning fields is an important practice to harvest high quality grass. However, there is a danger of workers being entrapped by smoke while they are working, and people set fireproof belts that effectively hinder the propagation of fire so that they can advance the work. Such fire belts are set by mowing every year; however, because the area is very huge, tremendous amount of labor is needed. To such fire belts, application of KATAMA™ SP[31] developed by Oita Works as weed proof measures is hoped and trial has been started in the Aso region, which is designated as "grass field special zone" as a part of National Comprehensive Special Zones for promoting regional vitalization policy.[32]

8.4 Application in forestry industry

8.4.1 Application as maintenance material for road system

Utilization rate of the forest that covers 67% of entire territory of Japan is regretfully low, and utilization rate of domestically produced timber remains low at 28%. Exhausting overseas forest, on the other hand, Japanese forest, which was once developed as business in forestry industry, is being devastated. Even in Oita Prefecture, where forestry industry was once prosperous, this situation remains the same, and it is said that forestry industry alone is not in a situation viable to afford the living of people.

Particularly, to perform maintenance work of forest, a road system is important; thus, Oita Prefecture has made numerous efforts to perform an effective maintenance of the road system because roads were damaged by heavy rains and ruts of heavy machinery, and driven by such repairing, a proper maintenance of forest itself could not be advanced.

Among them, KATAMA™ SP was innovated. It is a material that was originally developed since 2008 for use in the maintenance of forest roads. By compounding a steelmaking slag having the hydraulic property with a granulated blast furnace slag having a stronger latent hydraulic property, a material that exhibits stable strength was developed and introduced in Oita Prefecture. The prefecture approved it as a material for maintaining road system in forest and propagated its application throughout the prefecture through study course. Four years have already passed since then, and the material is used in many cases.[33]

The Oita Prefecture introduced "An example of works utilizing steelmaking slag as road base course material" at the presentation in Kyushu conference on forest conservation and forest road, held in Nagasaki on October 10th 2012, projected by an organization consisting of concerned administrative organizations. In the presentation, it was introduced that the material is a maintenance material capable of constructing a road system having high durability at a low cost. The presentation received "the Best Award honored by the Chairman of Forestry Research Center" and attracted attentions of other prefectures.

In addition, at "the 10th Symposium on Environment and Geotechnical Engineering," Professor Shin-ichiro Wada et al. of the Department of Agriculture of Kyushu University reported "Characteristics of change in paving material using iron and steelmaking slag and assessment of its influence on soil around the pavement" and the result of the assessment of a very low risk of influence on the environment in the application in forest was introduced.[34]

However, there still exist problems in application to forest. In a road system, in a section of a road system having a sharp inclination and is subjected to wear that wheels of carriages are causing, costly concrete is used, however, KATAMA™ SP can't be substituted for concrete because precisely speaking, the material is short of strength and rolling compaction is impossible at the construction section with a large inclination, strength at the completion stage is insufficient. Then, we developed G (great) KATAMA™ having strength higher than that of KATAMA™ SP, of which application test is being promoted with private and administrative organizations.

8.5 Application in marine products industry

Vivary™ unit, Vivary™ box, and Vivary™ rock, which have been recently tested and developed by Nippon Steel & Sumitomo Metal, were once assessed by Environmental Technology Verification (ETV) of the Ministry of the Environment, which made these products become well known among the related organizations of marine products industry, and inquiries from fishery cooperative associations and administrative organizations have increased. At Oita Works, the production system was established to cope with such situations and contributed to tests in Himeshima, Saiki, and stone-throwing project (artificial fish reef development project) in Kunisaki City.

Among them, the fixation of Vivary™ box is difficult when it is used in the open sea with high waves. Then, merchandise termed as Vivamex™ was developed jointly with Fudo Tetra Corporation (**Photo 8.5**). This merchandise was developed by filling with Vivary™ unit, the center opening of a PERMEX™,[35] which is the merchandise previously developed by Fudo Tetra (a block having five openings so that the buoyancy force is exerted to the block in a distributed manner, realizing very high stability), and developed for use in open sea with high waves.

Photo 8.5 Situation of experiment

Photo 8.6 Situation of experiment

This merchandise was used in the tests for the thick growth of red algae such as Ecklonia kurome, Meristotheca papulose, and Gelidium amansii (**Photo 8.6**) and used currently by Shimoirizu fishery cooperative association.

8.6 Conclusion

As environment varies regionally in Japan, which stretches to north and south, products, production method, and harvesting method in the fields of agriculture, forestry, and marine products are different regionally. In conjunction with this situation, there are experimental laboratories of forestry and marine products in many places, and optimum forestry and marine products industries are being developed independently. Similarly, the application of iron and steelmaking slags to forestry and marine products industries needs to be studied according to respective regionality. Efforts to utilize iron and steelmaking slags started in 2007 have been propagated to Kinki University, administrative organizations, JA-related organizations, and large-scale farmers and are advancing and gaining trust of regional communities (**Photo 8.7**).

Forestry and marine product industries in our country constitute the foundation of national potentiality and a national crucial issue, and it is at a big turning point. It will be our pleasure if a new application of iron and steelmaking slags advances in the regions where steelworks are situated, thereby contributing to the development of the nationwide primary industries.

Photo 8.7 Event in a certain area

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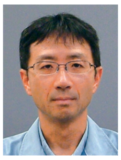
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