

I Markets and Fields with Demand for Iron and Steel Slag Products

1 Cement

Improvement in the Durability of Concrete Structures

The unique characteristics of iron and steel slag are being put to use in products used in various fields, with the largest demand being in cement. Approximately 50% of iron and steel slag products are used as cement raw



Blast-furnace slag cement is shipped in special transportation vehicles or in bags.

materials, and when considering only blast furnace slag, the percentage rises to about 70%.

Concrete using blast-furnace slag cement has greater long-term strength than concrete made with ordinary Portland cement, making it suitable for a variety of applications. Some other advantageous properties of concrete made with blast furnace slag include: suppression of alkali-aggregate reaction, high resistance to seawater and chemical substances, reduced risk of reinforcing bar corrosion due to chloride ions, low heat generation rate, and lower environmental impact.

Blast-furnace slag cement is highly valued for these properties and has been used in various marine and river structures such as revetments and dams, road and railroad structures, various civil engineering projects, building foundations, and ground improvement works. In civil engineering projects directly implemented by the Ministry of Land, Infrastructure, Transport and Tourism and the Ministry of Agriculture, Forestry and Fisheries, blast-furnace slag cement accounts for more than 90% of cement for ready-mixed concrete. This is mainly

Structures Using Blast-Furnace Slag Cement

Koyama Dam (Ibaraki Prefecture)



Akashi-Kaikyo Bridge



* CASBEE (Comprehensive Assessment System for Building Environmental Efficiency): A system to comprehensively evaluate the environmental performance of buildings, including the reduction of environmental impacts through energy and resource saving, as well as the improvement of environmental quality and performance such as comfort of indoor spaces and harmony with the building's surroundings. The system was developed in 2001 by a committee established within the Housing and Building SDGs Promotion Center under the leadership of the Ministry of Land, Infrastructure, Transport and Tourism.

due to the designation of blast-furnace slag cement as designated procurement items under the Act on Promoting Green Procurement, as well as their inclusion in the standard specifications for public works.

Recently, the use of blast-furnace slag cement has increased in building works. Blast-furnace slag cement is particularly suitable for piles, foundations, underground beams, and continuous walls, as these components generally have large member cross-sectional areas, allow for longer concrete curing periods, and have relatively concrete cover thickness. The use of blast-furnace slag cement for large-scale building works is also recommended in the Tokyo Metropolis Building Environmental Plan System and CASBEE (*), which is implemented by each municipality.

The system was started in Tokyo Metropolis in FY 2002, and to date, blast-furnace slag cement has been adopted in 30% of the specific buildings subject to the system.

Reduction in CO₂ Emissions

The Japanese cement industry emits CO₂ equivalent to approximately 4% of the country's total greenhouse gas emissions. Most of this CO₂ is generated during the production of clinker, an intermediate product of cement, through the calcination of limestone. Blast-furnace slag cement can reduce CO₂ emissions by significantly lowering the proportion of clinker, as it is produced by mixing a large amount of ground granulated blast-furnace slag with ordinary Portland cement.

As a measure against global warming, the government is promoting the use of blast-furnace slag cement. The Ministry of Economy, Trade and Industry has studied the "Measures to Promote and Expand the Use of Mixed Cement," and the "Expansion of the Use of Mixed Cement" has been incorporated as one of the policy measures in the "2030 Greenhouse Gas Reduction Target" plan, which was approved by the Cabinet in October 2021.

CO₂ Emission Reduction Effect by Blast-Furnace Slag Cement (Compared with Estimated Annual Value)

Annual CO₂ reduction through the production of blast-furnace slag cement: **3.6 million tons**

- CO₂ Absorption by Forests (840,000 ha) in Akita Prefecture (840,000 ha)



= 3.42 million tons

- CO₂ Reduction from Installing Photovoltaic Systems on Detached Houses (1.56 Million Units) in Aichi Prefecture



= 3.59 million tons

New National Stadium (2019)



Tokyo Metropolitan Government Building (1990)



2

Concrete Aggregate

Blast Furnace Slag Aggregate and Electric Arc Furnace Oxidizing Slag Aggregate

Concrete aggregate produced from iron and steel slag includes blast furnace slag aggregate and electric arc furnace oxidizing slag aggregate, each of which is available as both coarse and fine aggregate. Blast furnace slag coarse aggregate is produced by slowly cooling molten blast slag and adjusting its grading. Blast furnace slag fine aggregate is produced by rapidly cooling molten slag with water to form granulated slag, followed by grading adjustment. Electric arc furnace oxidizing slag aggregate is produced by slowly cooling molten slag extracted from an electric arc furnace or rapidly cooling it with water or air, followed by grading adjustment.

JIS standards for blast furnace slag aggregate were established in 1977 for coarse aggregate and in 1981 for fine aggregate. In addition, it has been incorporated into various guidelines of the Architectural Institute of Japan and the Japan Society of Civil Engineers, and is now widely used as one of the major types of concrete aggregate. JIS standards for electric arc furnace oxidizing slag aggregate were also established in 2003, and its use is gradually expanding.

Characteristics of Iron and Steel Slag Aggregate

Iron and steel slag aggregate is an industrial product produced under appropriate quality control. It has several advantages, such as not containing organic impurities, clay, or shells that can affect the durability of concrete; exhibiting minimal variation in quality.

In addition to these advantages, blast furnace slag fine aggregate has recently attracted attention for its ability to

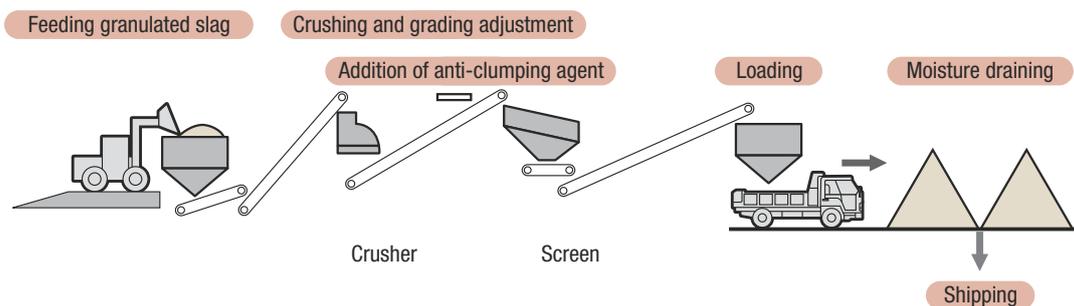
suppress the drying shrinkage of concrete and to improve sulfuric acid resistance and freeze-thaw resistance. When combined with appropriate mix design and construction practices, it is expected to contribute to improved concrete durability. Electric arc furnace oxidizing slag aggregate, which has a high oven-dry density of approximately 3.6 g/cm³, significantly higher than that of other aggregates, has been used in radiation shielding concrete and heavyweight concrete, taking advantage of this characteristic.

With the 2013 revision of the JIS standards for both types of aggregate, provisions on elution amounts and content were introduced from the perspective of environmental safety. As a result, they are now recognized as safe materials for use in concrete.

Contribution to Environmental Preservation as an Alternative to Natural Aggregate

Triggered by the complete ban on sea sand extraction in the Seto Inland Sea in 2006 and the reduction in imported sand due to the embargo on Chinese sand, social demand for measures to address the depletion of natural aggregates increased significantly, leading to a sharp rise in the sales volume of iron and steel slag aggregate. Blast furnace oxidizing slag aggregate and electric arc furnace oxidizing slag aggregate were selected as designated procurement items under the Act on Promoting Green Procurement in FY 2002 and 2005, respectively. They are highly regarded as environmentally friendly materials that contribute to environmental conservation by suppressing the exploitation of natural resources, reducing energy consumption during natural resource extraction, and lowering the associated CO₂ emissions.

Example of the Production Process of Blast Furnace Slag Fine Aggregate



Fine Aggregate and Coarse Aggregate



Blast furnace slag fine aggregate



Blast furnace slag coarse aggregate



Electric arc furnace oxidizing slag fine aggregate



Electric arc furnace oxidizing slag coarse aggregate

Application Example



Interlocking blocks (made with blast furnace slag fine aggregate) laid at Meriken Park, Kobe Port.



Precast blocks (made with blast furnace slag fine aggregate) used in the revetment work at Hiroshima Port



Wave dissipating blocks (made with electric arc furnace oxidizing slag aggregate)

Characteristics of Iron and Steel Slag Aggregate

- Industrial products with uniform chemical components free from organic impurities, clay, and shells.
- Contributes to the preservation of precious natural resources by being used as alternatives to natural gravel and crushed stone.

3

Roads

Excellent Durability and Cost-effectiveness

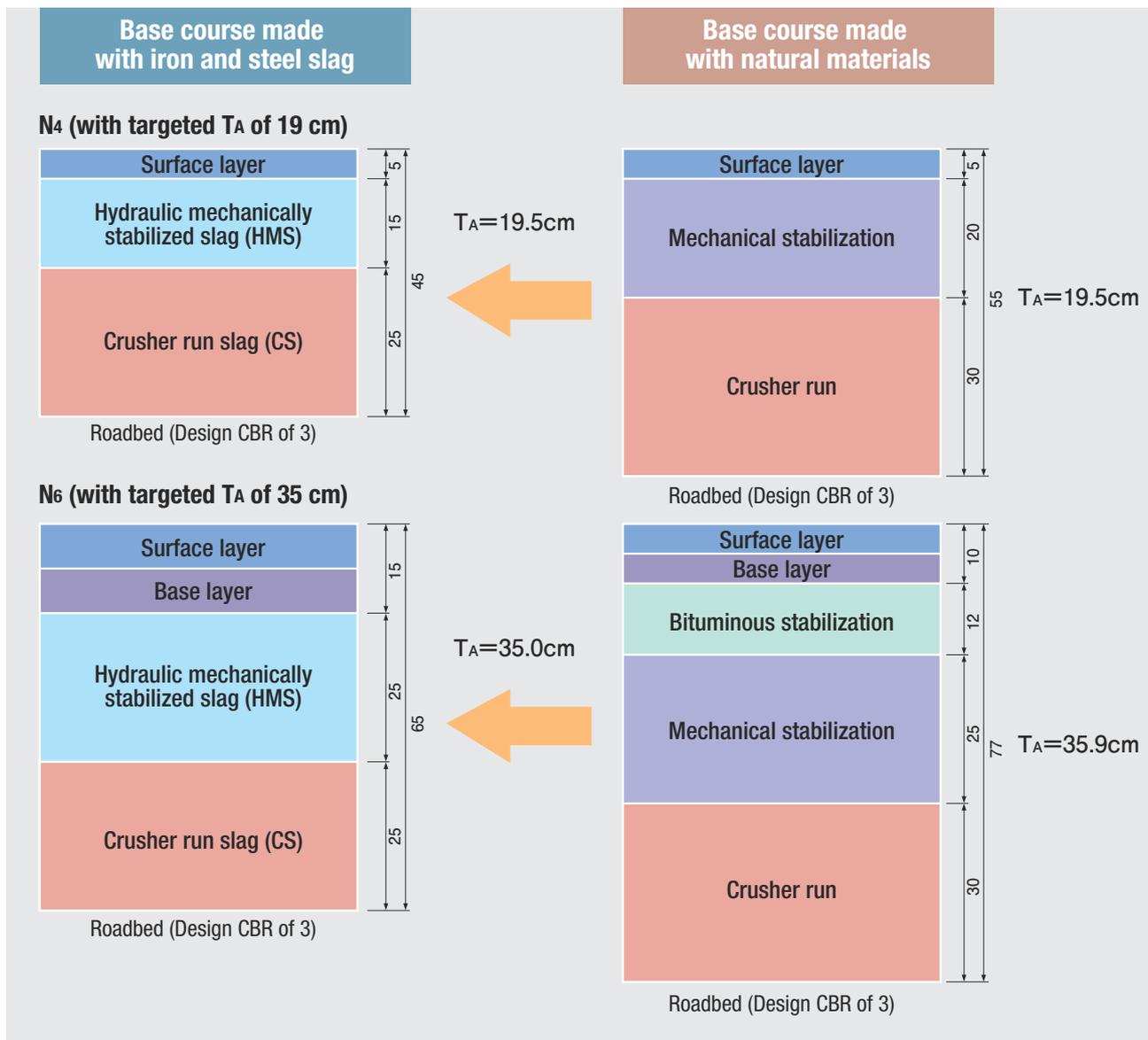
Iron and steel slag for road construction is produced by crushing blast furnace slag and steelmaking slag, followed by grading adjustment to create paving materials. These materials include base course materials, which can be used either alone or in combination with other materials, and asphalt mixture aggregates made from steelmaking slag.

Research on using iron and steel slag as road construction materials began in the 1960s, leading to the development

of key technologies such as aging techniques and particle size composition. As a result, design and construction guidelines were established, and iron and steel slag was incorporated into the Manual for Asphalt Pavement. Additionally, JIS standards were established in 1979 and, through several revisions—including the incorporation of quality standards from the perspective of environmental safety, have evolved into the current JIS A 5015.

Hydraulic mechanically stabilized slag “HMS-25 (*),” a typical iron and steel slag base course material, hardens over a long period. By utilizing its unique characteristics, it allows for a thinner base course cross-section compared

Comparison Between Iron and Steel Slag Base Course Material and Natural Material



* HMS-25: An upper base course material made from iron and steel slag with grading adjusted to 0–25 mm.

to general crushed stone (mechanically stabilized stone). Additionally, hydraulic mechanically stabilized slag allows for immediate traffic access after construction and enables base course compaction to be continued even if it rains—an excellent level of workability that is highly praised. Besides being used as a base course material, steelmaking slag is also used as an aggregate in asphalt mixtures due to its superior hardness and abrasion resistance.

In FY 2002, base course materials mixed with iron and steel slag and asphalt mixtures containing iron and steel slag were selected as designated procurement items under the Act on Promoting Green Procurement. As a result, they have been widely recognized as materials that contribute to environmental preservation.

Aging as Solution for Yellow Water and the Measure Against Expansion and Powdering

Sulfur turns yellow and emits a hot spring-like odor when it comes into contact with water. To prevent these phenomena, blast furnace slag undergoes aging, during which sulfur is either oxidized into stable thiosulfate ions or sulfate ions by reacting with air, or neutralized with carbon dioxide gas to eliminate the yellow color and odor of the water. Aging is carried out by making piles of freshly crushed and screened slag in a yard until it stabilizes.

Steelmaking slag also undergoes aging. Quicklime used in the refining of steelmaking raw materials (pig iron and scrap) may remain in the slag in an unstable state if not sufficiently dissolved. This insufficiently dissolved quicklime, known as free lime, expands in volume when it reacts with water and may cause a phenomenon called pop-out, in which the asphalt is pushed up from below, damaging the surface. In order to prevent this phenomenon, aging is used to react the free lime with moisture in advance, converting it into hydrated lime and thereby stabilizing its volume. Aging can be carried out either by accelerating the reaction using high-temperature of steam or high-pressure steam and water, or by piling the crushed slag in a yard until it stabilizes.

The standard value for the immersion expansion ratio, an indicator used to evaluate expansion stability, was reviewed when the “Guidelines for the Design and Construction of Iron and Steel Slag Road Base Course” were published in 2015 (Heisei 27), and the standard was tightened from 1.5% to 1.0%.

Construction Example



Base course material mixed with iron and steel slag

Usage Example



Higashi-Kyushu Expressway
(provided by West Nippon Expressway Company)



Higashi-Kyushu Expressway
(provided by West Nippon Expressway Company)

4 Civil Engineering and Port Works

Lighter than Natural Sand

Granulated slag for civil engineering works is used for backfilling behind revetments, covering soil for soft ground improvement, roadbed, and embankment construction.

Sandy granulated slag has physical and mechanical properties such as being lighter than natural sand and having a larger angle of shear resistance. In addition, it possesses hydraulicity, meaning it hydrates and solidifies over time, which increases its resistance to liquefaction during earthquakes. When granulated slag is used as a backfill or behind-revetment material, its light weight and large angle of internal friction significantly reduce the active earth pressure acting on front-facing sheet piles, allowing for a reduction in the cross-sectional dimensions of the sheet piles.

Additionally, once fully solidified, granulated slag does not undergo liquefaction during earthquakes, thereby eliminating the need for liquefaction countermeasures. When used as covering soil for soft ground improvement, its properties, such as being lightweight, unaffected by water, and having excellent trafficability, help reduce the risk of lateral flow in soft layers and the amount of consolidation settlement.

Roadbeds constructed with granulated slag are lightweight and suitable for soft ground, exhibiting sufficient bearing capacity without undergoing significant deformation under traffic loads.

Additionally, granulated slag exhibits hydraulicity, which

prevents strength reduction caused by water infiltration even under repeated traffic loads. As a result, it offers not only excellent economic efficiency and workability, but also superior durability as a road structure material.

When used for embankment construction, granulated slag's light weight and large angle of shear resistance can offer design advantages, especially in embankment work on soft ground.

Cost Reduction through Lightweight Backfill Material:

Quay Wall at Asuka Pier South District, Port of Nagoya

The container terminal on the south side of Tobishima Pier in the Port of Nagoya, which entered service in 2005, features earthquake-resistant quay walls with a water depth of 16 meters. It is one of the largest container terminals in Japan, capable of accommodating container ships exceeding 10,000 TEUs (*).

By redesigning the backfill material for the quay wall from crushed stone to granulated slag, it was possible to reduce the cross-sectional dimensions of the front-facing steel pipe piles and anchor piles, resulting in a significant reduction in construction costs (approximately 18% reduction, according to figures published by the Nagoya Port Office of the Ministry of Land, Infrastructure, Transport and Tourism).

Settlement Countermeasures for Ultra-Soft Ground: Kitakyushu Airport

Approximately 1.5 million tons of granulated blast furnace slag were used for soft ground improvement works at Kitakyushu Airport between 2000 and 2002.

Kitakyushu Airport was constructed approximately 3 kilometers offshore in Suō-nada, using dredged soil generated from waterway development in Kitakyushu Port, Kanda Port, and other nearby areas for land reclamation. As a result, settlement countermeasures for ultra-soft ground were required. It is said that dredged soil takes a considerable amount of time to become strong ground under natural conditions.

To quickly strengthen the ultra-soft ground, a sand mat was installed and ground improvement was carried

Characteristics of Granulated Slag for Civil Engineering Works

- **Lighter than natural sand**
(Wet unit volume weight of 11 to 16 kN/m³)
- **Angle of shear resistance of 35 degrees or more, with a design CBR of 20 to 30%, providing greater strength than natural sand**
- **Hydraulicity improves long-term strength and durability**
- **Hydraulic conductivity of 10⁻² to 10⁻⁴ m/s before solidification, equivalent to or better than high-quality sand**

* TEU: A unit indicating the loading capacity of a container ship; 1 TEU is equivalent to one 20-foot container.

out using the paper drain method during airport construction. Because granulated blast furnace slag is lighter than natural materials, it was evaluated as effective in reducing settlement in reclaimed land and was adopted as part of the sand mat material. In the first construction area off the coast of Shin-Moji, a 60 cm thick layer of granulated blast furnace slag (approximately 550,000 m³) was placed over a 90 cm thick sea sand layer. In the second construction area, a 90 cm thick layer of granulated blast furnace slag (approximately 650,000 m³) was laid over a 90 cm thick sea sand layer.

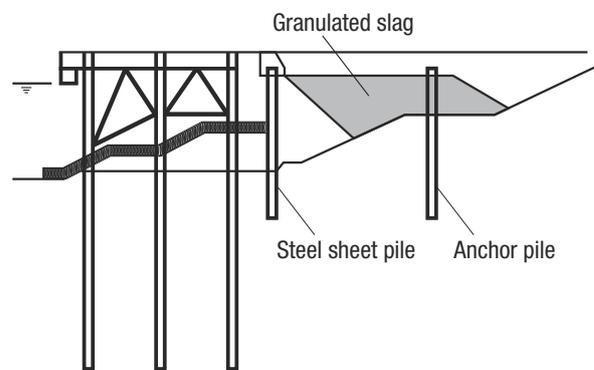
Kitakyushu Airport



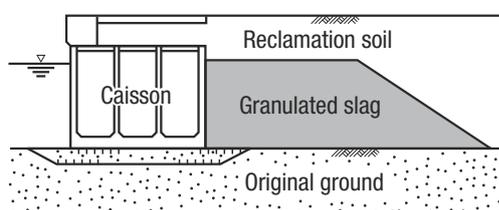
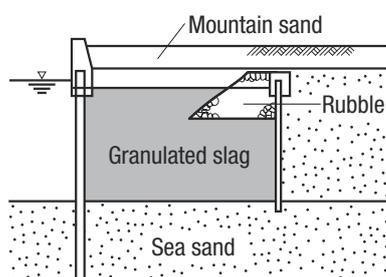
Tobishima Pier in the Port of Nagoya



Quay Wall at the Tobishima Pier South District in the Port of Nagoya



Backfilled Steel Sheet Piles and Caisson Piles



5

Ground Improvement

Verification of Impacts on Surrounding Sea

Since FY 1993, the Nippon Slag Association, in collaboration with the Coastal Development Institute of Technology (CDIT), has been conducting research on the application of steelmaking slag as a material for port construction. In 2000, the “Guidebook for the Use of Steelmaking Slag in Port Construction” was published. Later, in February 2015, CDIT released the “Technical Manual for the Use of Steelmaking Slag in Ports, Airports, and Coastal Areas.”

This research examined not only the physical properties of steelmaking slag, but also its impact on the marine environment through experimental construction of on-land sand compaction piles (SCPs) at Kobe Port Island and offshore SCPs at Hiroshima Port. An SCP is a ground improvement method that enhances the strength of soft ground by installing compacted sand piles. The research confirmed that steelmaking slag for ground improvement can help reduce construction costs by taking advantage of its geotechnical properties; specifically, a higher unit volume mass and larger angle of shear resistance compared to natural sand.

Additionally, regarding the environmental impact of applying steelmaking slag in marine areas, it has been confirmed that although leachate from steelmaking slag typically has a high pH, when used as infill material for SCPs, it is enclosed within casing pipes during installation and has minimal direct contact with seawater. As a result, little to no increase in the pH of the surrounding marine environment has been observed.

Following its evaluation as a viable alternative to natural sand for use in SCP materials, steelmaking slag has been utilized in port construction projects across Japan (see table on P44). Particularly in areas such as the Seto Inland Sea, the use of steelmaking slag for ground

improvement as SCP infill material has rapidly expanded, partly due to the growing number of municipalities that have banned sea sand extraction for environmental conservation reasons.

In the development of the multi-purpose international terminal quay wall (–11 m) at the Higashi-Sakae District of Otake Port in Hiroshima Prefecture, the SCP method using steelmaking slag as infill material was adopted for ground improvement of an approximately 20-meter-thick alluvial clay layer beneath the gravity-type revetment, with an improvement area ratio of 70%. As a result, construction costs were reduced by approximately 5%. Additionally, it was confirmed that all environmental standards were met through environmental monitoring during the construction period, and elution tests for the materials used were conducted in accordance with the Act on Prevention of Marine Pollution and Maritime Disasters, with all results meeting the required criteria.

Use of Steelmaking Slag for Liquefaction Countermeasures:

Nabeta Pier Quay Wall in the Port of Nagoya

One example of the use of steelmaking slag in the on-land SCP method is the ground improvement work of the Nabeta Pier quay wall (–12 m) at the Port of Nagoya in 2009. Because steelmaking slag offered workability equivalent to that of natural sand and lower material costs, it contributed to an overall cost reduction of approximately 10%. (Source: Ministry of Land, Infrastructure, Transport and Tourism, Chubu Regional Development Bureau, “Public Works Cost Structure Improvement Program” [Policy name: II. Optimization of Planning, Design, and Construction; (2) Review of Construction Methods – Measure 11: Cost Improvement through Material Substitution])

Characteristics of Steelmaking Slag for Ground Improvement

- **Angular in shape with a coarse surface, similar to natural crushed stone or sand**
- **With a particle density of 3.2 to 3.7 g/cm³, higher than that of natural stone materials, and a unit volume mass of 19 to 26 kN/m³ in wet conditions (at 5% water content) and 14 to 16 kN/m³ underwater, it is relatively heavy.**
- **Angle of shear resistance of 40 degrees or more**

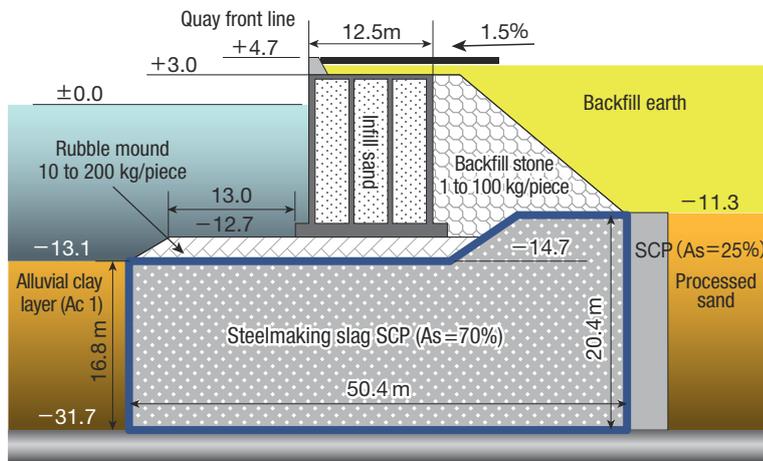
Development of Multi-Purpose International Terminal Quay Wall (-11 m) at the Higashi-Sakae District of Otake Port in Hiroshima Prefecture



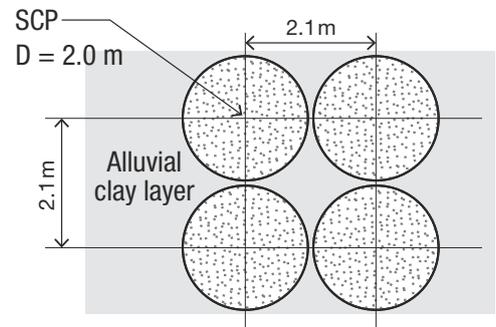
Offshore SCP Installation Work



Entire View of Quay Wall at the Higashi-Sakae District of Otake Port
(Source: Webpage of the Hiroshima Bay Renaissance Project)



Section of Quay Wall at Higashi-Sakae District in Otake Port

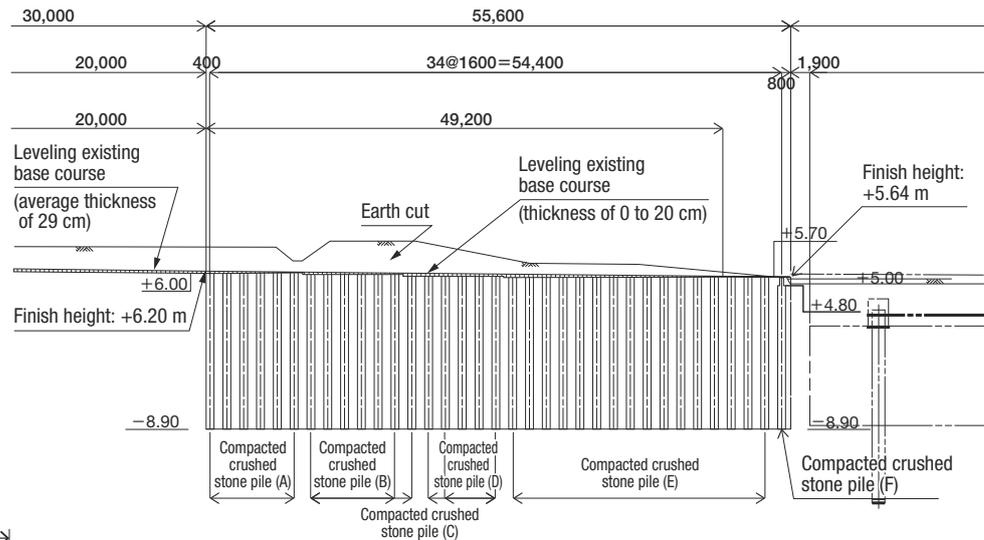


SCP Layout Plan

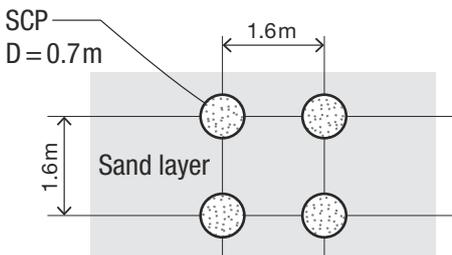
Ground Improvement Work for Nabeta Pier Quay Wall (-12 m) in the Port of Nagoya



On-land SCP Installation Work



Example of the Section of Steelmaking Slag SCP



SCP Layout at Nabeta Pier

6

Fertilizers

The Ministry of Agriculture, Forestry and Fisheries established the standards for fertilizers made from iron and steel slag under the Act on the Quality Control of Fertilizer. The main types of standardized fertilizers include mineral silicate fertilizer, byproduct lime fertilizer, slag phosphate fertilizer, and byproduct fertilizer. Among the types of iron and steel slag, blast furnace slag contains fertilizer components such as calcia (CaO), silica (SiO₂), and

magnesia (MgO). In addition to calcia, silica, and magnesia, steelmaking slag contains iron(II) oxide (FeO), magnesia (MnO), and phosphorus(V) Oxide (P₂O₅).

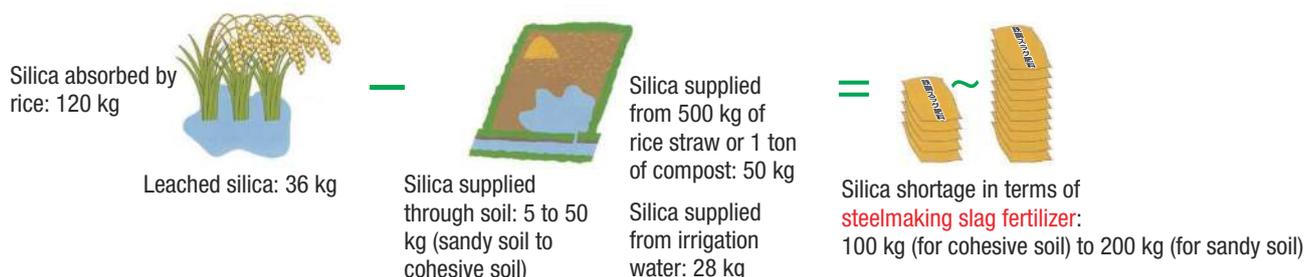
Fertilizers made from blast furnace slag are mainly used for rice cultivation, while those made from steelmaking slag are widely used not only for rice cultivation but also for field crop and pasture cultivation.

Required amount of silicic acid (per 10 acres)

Silica uptake: 156 kg

Silica supplied: 83 to 128 kg

Total silica shortage: 28 kg to 73 kg



Effects on Rice Cultivation

(Blast Furnace Slag Fertilizer and Steelmaking Slag Fertilizer)

Application of Iron and Steel Slag Fertilizer

Effects of Silicic Acid

- ① Improvement light-receiving posture of leaves and enhancement of photosynthesis
- ② Strengthening of stems, thereby preventing lodging
- ③ Hardening of leaves and stems, thereby inhibiting the invasion of rice blast fungus and rice stem borers

- ④ Silicon accumulates beneath the cuticle layer of the epidermis, suppressing cuticular transpiration and maintaining stomatal transpiration even under high temperatures, thereby reducing the rise in rice plant temperature.
- ⑤ Promoting root oxidation, thereby enhancing root vitality

Effects of Alkaline Content

- Increasing soil pH
- Promoting the decomposition of rice straws through pH adjustment
- Maintaining a pH level suitable for crop growth

Effects of Iron and Manganese (Steelmaking Slag Fertilizer)

- Preventing root rot by suppressing abnormal reduction

High temperature damage to paddy rice during the ripening period causes significant reductions in both the quality and yield of rice.

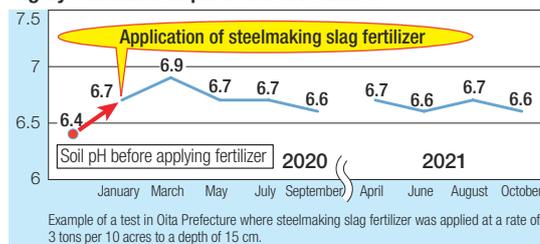
The importance of soil preparation fertilizers, including slag fertilizers, is currently being re-evaluated.

Effects on Field Crop Cultivation (Steelmaking Slag Fertilizer)

Clubroot, Phomopsis root rot, and Fusarium disease are typical soil-borne diseases caused by pathogenic bacteria in the soil that infect plant roots and cause the aboveground parts of plants to wilt. Since these pathogens prefer acidic soils, applying alkaline substances to the soil and adjusting the pH to 7.0–7.5 can suppress the onset of these diseases. However, raising the pH too much is likely to cause deficiencies in micronutrients such as manganese and boron.

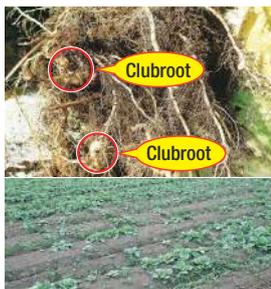
Steelmaking slag fertilizers contain not only alkaline components that can improve and maintain soil pH but also minerals such as iron, magnesium, manganese, and boron, which promote the vitality of agricultural crops.

Highly Sustainable pH Corrective Effect



Effects of Slag Fertilizer on Chinese Cabbage
Steelmaking slag fertilizer was applied to a field with a soil pH of 5.7 to adjust it to 7.5.

● Clubroot infected field (disease incidence rate of 65%)



● Steelmaking slag field (disease incidence rate of 0%)



Results in the test fields of the Oita Prefectural Agriculture, Forestry and Fisheries Research Center Usage of steelmaking slag fertilizer: 28 tons/10 ares to a depth of 20 cm.

* It is recommended to determine the application rates by consulting with agricultural advisors regarding the soil in question and the pH buffering curves of steelmaking slag fertilizers.

Steelmaking slag fertilizers contribute to supplying minerals such as iron, magnesium, and manganese to crop fields, as well as improving and maintaining soil pH.

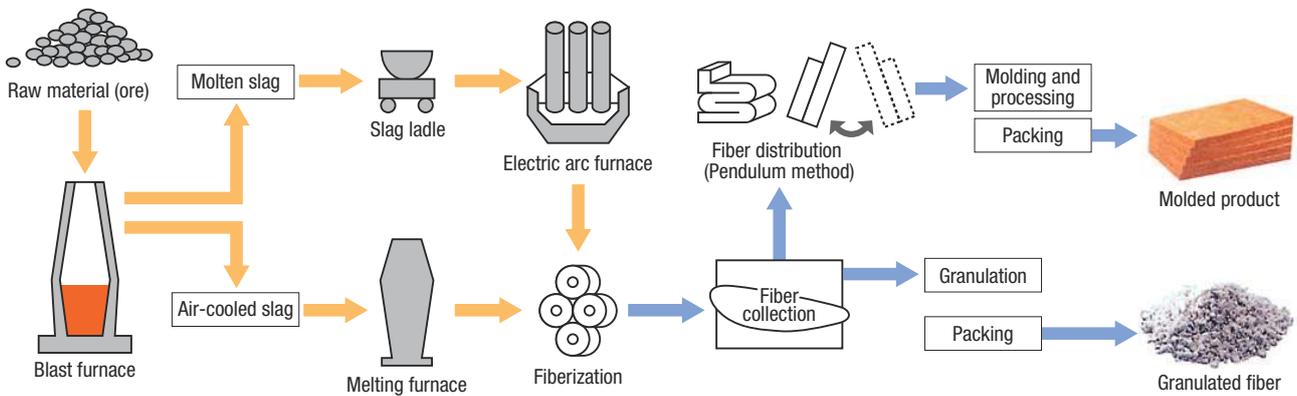
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Rock Wool

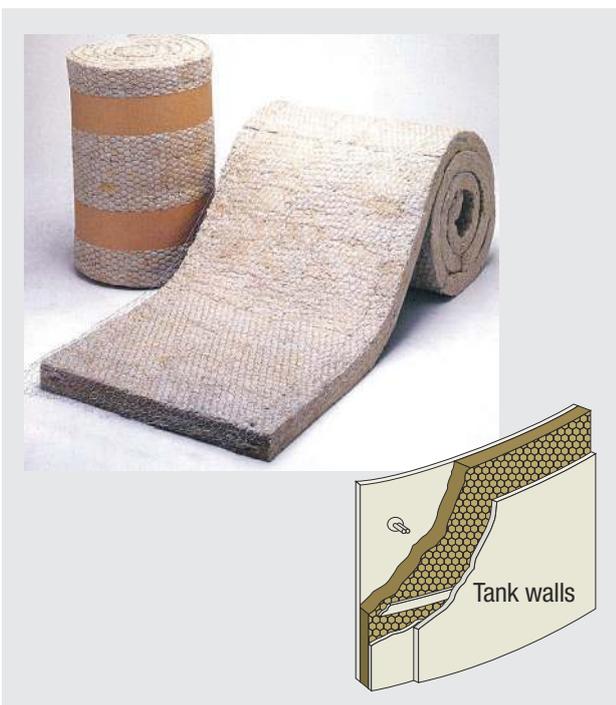
Rock wool is produced from blast furnace slag and other types of slag by melting the slag at high temperatures in a cupola or electric arc furnace, and then blowing the molten slag into a fibrous form. Fibrous rock wool is collected in a fiber collection room, then defibrated and granulated into

granular fiber. It is then processed by adding a binder and hardening in a curing furnace, after which it is adjusted to a specific density and thickness to be made into molded products such as boards and mats for housing.

Diagram of Production Process



Rock Wool and its Cross Section



Application Example of Rock Wool

Filled insulation



External insulation

