Environmental Materials

Iron and Steel Slag

S L A G

NIPPON SLAG ASSOCIATION

FS-209

I N T R O D U C T I O N

Iron and Steel Slag: Earth-friendly material

Iron and steel slag products are currently produced and quality-controlled for various applications, ensuring they meet environmental safety and quality standards. Furthermore, the majority of these iron and iron and steel slag products are now available in the market as either Japan Industrial Standards (JIS)-compliant items or as designated procurement items under Green Procurement. As a result, iron and steel slag products play a significant role as construction materials supporting infrastructure such as roads, ports, and airports across Japan, and as environmental materials contributing to the restoration and improvement of the environment, including the sea, soil, and other areas.

Japan has a history of iron and steel slag use spanning approximately 100 years. Following the start of Asia's first integrated steelmaking at the government-operated Yawata Steel Works in 1901, the test production of blast-furnace slag cement began in 1910. Along with the expansion of steel production, the development of applications for iron and steel slag has been actively promoted.
With the development of Japan's steel industry, iron and steel slag was primarily used as construction materials at coastal steelworks until the 1960s. After the completion of steelworks construction, the commercialization of iron and steel slag products rapidly advanced in response to the societal needs for energy conservation and resource saving following the oil crisis of 1973. Since then, iron and steel slag has been used in a wide range of applications up to the present day.

In the steelmaking process, producing high-quality iron and steel slag is now regarded as a crucial element in the operation and facility design of steel production. Currently, approximately 99% of iron and steel slag is recycled into resources. Additionally, iron and steel slag products that meet various quality requirements from customers can now be supplied. During this time, with support from the government, local municipalities, related academic associations, and various other sectors, efforts have been made to promote technological development, establish production and processing facilities, and conduct public recognition activities aimed at the widespread use and promotion of iron and steel slag applications.

Steel Slag as Environmental Materials in the 21st Century

With regard to iron and steel slag, we believe that responding to environmental issues and to structural changes in supply and demand will continue to be major themes going forward.

The structural changes in supply and demand are driven by an increase in the amount of iron and steel slag generated on the one hand, and a decrease in demand on the other. Since entering the 21st century, the Japanese steel industry has shown steady performance. Although there were temporary downturns, it has followed a recovery path backed by its international competitiveness, and the production volume of iron and steel slag has also remained stable. On the other hand, the decline in demand for iron and steel slag is accelerating due to the continued contraction of the domestic construction market, its primary application, reductions in public investment aimed at fiscal reconstruction, and decreases in both the population and the number of households.

In this context surrounding iron and steel slag, the most important issue is considered to be the further strengthening of management practices for iron and steel slag products. Furthermore, even in the challenging market environment characterized by a decline in construction investment, we will actively and boldly promote efforts to expand the demand for iron and steel slag by further unlocking its potential in various fields.

Iron and steel slag products, which contribute to resource and energy conservation as well as CO_2 emission reduction, are environmental materials that represent the 21st century, the dawn of the global environmental era. In October 2020, the Japanese government declared its goal to achieve carbon neutrality by 2050, aiming to reduce the overall emissions of greenhouse gases to zero. To achieve this goal, further strengthening of CO_2 emission reduction is required. In response to this need, we are confident that the characteristics of iron and steel slag products can be fully leveraged.

We hope this booklet will serve as a useful tool in helping a wider audience gain a more accurate understanding of the usefulness of iron and steel slag products along with the efforts in the steel industry regarding iron and steel slag.

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I What is Iron and Steel Slag?

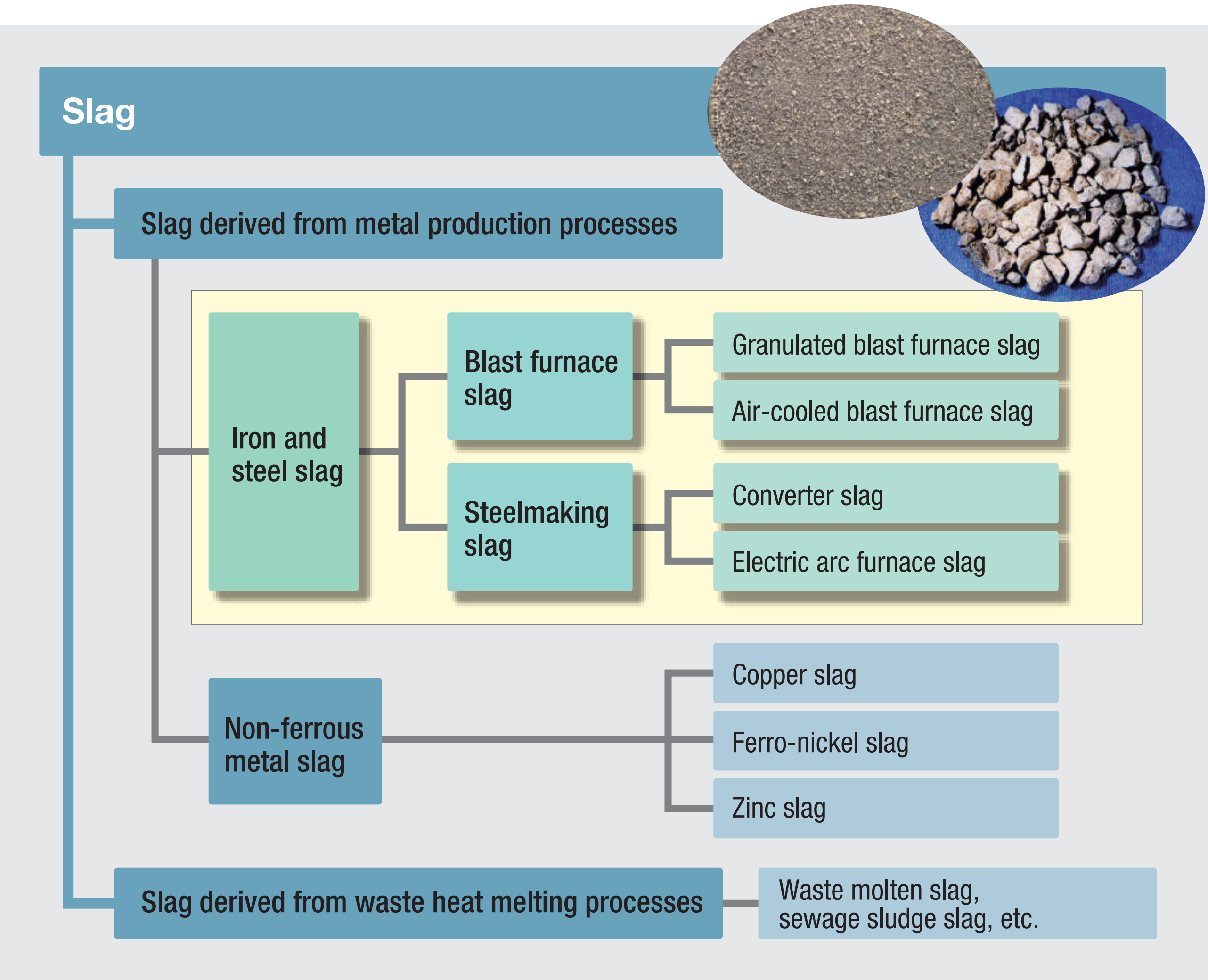
1 Types of Slag:
Slag Derived from Metal Production Processes and Slag Derived from Waste Heat Melting Processes

Slag is produced when specific components are melted and separated during the reduction and refining of metal from ores.

Slag originally refers to substances derived from metal production processes. However, in recent years, substances generated from waste incineration facilities through waste heat melting processes are also referred to as slag. Furthermore, slag from metal production processes is classified into iron and steel slag and non-ferrous metal slag. Iron and steelmaking slag specifically refers to slag produced during the production of steel products.

Iron and steel slag is a by-product formed when components other than iron, such as silica (SiO_2), melt and combine with lime (CaO) during the reduction and refining stages of steel production from iron ores. Iron and steel slag is utilized as an "earth-friendly material" capable of achieving energy and resource conservation, as well as CO_2 reduction.

Types of Slag



2 Processes Involved in the Production of Iron and Steel Slag

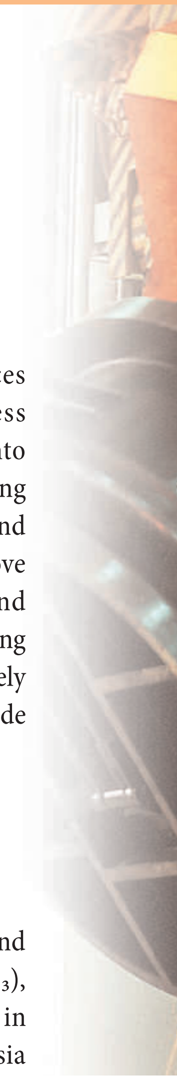
Limestone, an auxiliary raw material in steelmaking, as the origin of iron and steel slag

Although limestone may initially seem unrelated to steelmaking, it is an essential auxiliary raw material in the steelmaking process.

The limestone traditionally used by the Japanese steel industry has been mined domestically. Coral reefs and limestone on the oceanic plate in the Pacific were incorporated into the ground of the Japanese archipelago as one plate moved under another along the archipelago. Japan still boasts a rich limestone reserve to this day. Japanese limestone, formed in the vast ocean with few impurities, is even exported overseas due to its high quality.

Limestone is added during the reduction of iron ore to remove impurities such as silica and alumina (Al_2O_3) present in the ore. As it combines with these impurities, limestone forms a molten substance with a low melting point, which facilitates the separation and collection of these impurities from the iron. The collected material becomes iron and steel slag.

Limestone



Processes of Iron and Steel Slag Formation

Iron and steel slag can be broadly classified into blast furnace slag, which is produced during the melting and reduction of iron ores in blast furnaces, and steelmaking slag, which is produced during the refining stage of iron.

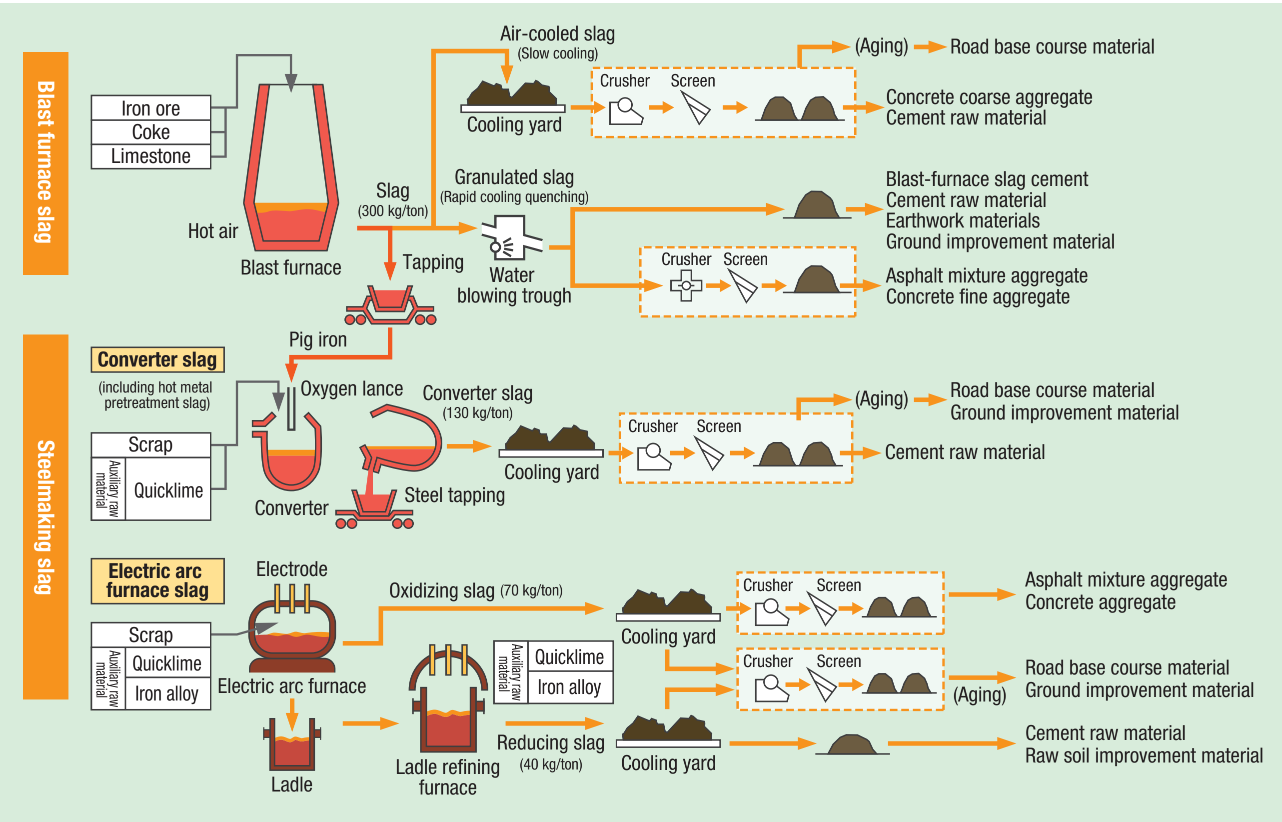
Blast furnace slag is produced when components other than iron in iron ores, such as silica, and the ash content of coke used as a reduction material combine with limestone. In its molten state, blast furnace slag floats on the surface of pig iron, making it easy to separate and collect. Approximately 300 kg of blast furnace slag is produced per ton of pig iron. The slag extracted from the blast furnace is in a molten state at approximately 1,500°C and forms different types of slag with varying characteristics depending on the cooling method **(see p.10 for details)**.

Steelmaking slag is produced in the steelmaking process, which converts pig iron generated in blast furnaces into steel, which is known for its high toughness and machinability. Steelmaking slag is classified into converter steelmaking slag, which is produced during the refining process of pig iron by blowing oxygen and adding auxiliary raw materials such as lime to remove impurities like carbon, phosphorus, and sulfur, and electric arc furnace slag, which is produced when melting and refining iron scrap **(see p.11 for details)**. Approximately 120 kg of steelmaking slag is produced per ton of crude steel.

Chemical Composition of Iron and Steel Slag

Iron and steel slag primarily consists of lime (CaO) and silica (SiO_2). Other components include alumina (Al_2O_3), magnesia (MgO), and a small amount of sulfur (S) in blast furnace slag, and iron oxide (FeO) and magnesia

Iron and Steel Slag Products Production Flow



(Note) In blast furnaces producing pig iron and blast furnace slag, recycled resources such as waste plastic are effectively utilized as auxiliary raw materials.

(MgO) in steelmaking slag.
In the case of steelmaking slag, many metal elements are incorporated into the slag in the form of oxides. Because of the short refining time and high lime content, some of the limestone in the auxiliary raw materials may remain undissolved as free lime (free-CaO).
These components naturally exist in the Earth's crust, natural rocks, minerals and the chemical composition is similar to that of ordinary Portland cement. The shape and physical characteristics of iron and steel slag are similar to those of crushed stone or sand. However, a wide variety of unique characteristics can be given to slag by using different chemical components and cooling processes. For example, some types of slag have a hardening characteristic when stimulated by alkalinity. In this way, various applications have been developed that take advantage of the physical and chemical characteristics of slag and they have been used in a wide range of fields.

Example Compositions of Iron and Steel Slag

(Unit: mass %)

Type / Component	Blast furnace slag	Converter slag	Electric arc furnace slag		Andesite	Ordinary Portland cement
			Oxidizing slag	Reducing slag		
CaO	41.7	45.8	22.8	55.1	5.8	64.2
SiO_2	33.8	11.0	12.1	18.8	59.6	22.0
T-Fe	0.4	17.4	29.5	0.3	3.1	3.0
MgO	7.4	6.5	4.8	7.3	2.8	1.5
Al_2O_3	13.4	1.9	6.8	16.5	17.3	5.5
S	0.8	0.06	0.2	0.4	—	2.0
P_2O_5	<0.1	1.7	0.3	0.1	—	—
MnO	0.3	5.3	7.9	1.0	0.2	—

II Types and Characteristics of Iron and Steel Slag

1 Blast Furnace Slag (Air-cooled and Granulated)

Blast furnace slag is produced when the components of iron ores other than iron, which are melted in blast furnaces to produce pig iron, along with limestone from the auxiliary raw materials and the ash content of coke, are collectively separated and recovered. Approximately 300 kg of blast furnace slag can be produced from one ton of pig iron. The slag removed from a blast furnace is in a molten state at approximately 1,500°C. Depending on the cooling method used, blast furnace slag is classified into air-cooled slag and granulated slag, each having different properties.

[Air-cooled slag]
Crystalline and rocky air-cooled slag is produced when molten slag is poured onto a cooling yard and undergoes slow natural cooling with some water spraying.

[Granulated slag]
Glassy and granular granulated slag is produced when molten slag undergoes rapid cooling by quenching with pressurized water injected into it.

Air-cooled slag

Granulated slag

Blast furnace

2 Steelmaking Slag (Converters and Electric Arc Furnaces)

Steelmaking slag is produced in the steelmaking process, which adjusts components of pig iron and scrap to produce steel, which has high toughness and machinability. Steelmaking slag is classified into converter slag produced from converters and electric arc furnace slag produced in the electric arc furnace steelmaking process using scrap as a raw material.
Converter slag is processed after undergoing natural cooling or water spraying on a cooling yard, similar to air-cooled blast furnace slag, after which it can be used for various applications. Approximately 130 kg of converter slag can be produced from one ton of converter steel. In recent years, the hot metal pretreatment which removes phosphorate (P) and sulfur (S) in the converter refining pre-process has become widely adopted, and the slag produced through this process is also classified as converter slag.
Electric arc furnace slag is produced when melting and iron scrap and refining and it is classified into oxidizing slag produced through oxidation refining and reducing slag produced through reduction refining. Until around 1980, both oxidation and reduction refining were performed in one electric arc furnace, making it difficult to separate oxidizing slag and reducing slag. Since then, ladle refining furnaces have been widely adopted, allowing for a clear separation of the oxidation refining and reduction refining processes, making it possible to separately produce oxidizing slag and reducing slag. Currently, approximately 70 kg of electric arc furnace oxidizing slag and 40 kg of electric arc furnace reducing slag can be produced from one ton of electric arc furnace steel.

Steelmaking slag (converter)

Converter

Electric arc furnace

3 Characteristics and Applications of Iron and Steel Slag

[Air-cooled blast furnace slag]

Air-cooled blast furnace slag has a hydraulic property in which the slag hardens through a reaction with water and increases its strength over time. Therefore, it is used as a base course material like gravel, as it is expected to have a large bearing capacity for civil engineering structures. With no risk of causing an alkali-silica reaction(*) and no inclusion of clay and organic impurities, air-cooled blast furnace slag is used as concrete coarse aggregate, just like natural aggregate.

[Granulated blast furnace slag]

Similar to air-cooled blast furnace slag, granulated blast furnace slag has a hydraulic property with no risk of causing the alkali-silica reaction. Due to its latent hydraulic property which can be significantly increased when finely granulated, it has been used in applications like making blast-furnace slag cement. When mixed with cement in approximately equal amounts, ground granulated blast furnace slag can be processed into blast-furnace slag cement that is equivalent to ordinary Portland cement (Portland cement), with its strength increasing over a long period. Taking advantage of its characteristics such as a slow heat generation rate when reacted with water and high chemical durability, it has been widely used in large-scale civil engineering works such as port construction.

[Steelmaking slag]

Steelmaking slag also has a hydraulic property, and so can also be expected to have a large bearing capacity as civil engineering structures. For this reason, it is also used as a base course material. As it excels in abrasion resistance due to its high particle density and hardness, it has been used as asphalt concrete aggregate. Additionally, due to a large angle of shear resistance, high particle density, and high unit volume weight, steelmaking slag has been used as earthwork materials and ground improvement materials (such as a sand compaction pile material).

Major Characteristics and Applications of Iron and Steel Slag

		Characteristics	Application
Blast furnace slag	Air-cooled slag	Hydraulic property Free from alkali-silica reaction Low Na_2O and low K_2O Heat insulation, heat retention, sound absorbing characteristics when fiberized Fertilizer component (CaO and SiO_2)	Base course material Concrete coarse aggregate Cement clinker raw material (alternative to clay) Rock wool raw material Calcium silicate fertilizer
	Granulated slag	Strong latent hydraulic property when finely granulated Low Na_2O and low K_2O Latent hydraulic property Light-weight, large angle of shear resistance, high water permeability Free from alkali-silica reaction Fertilizer component (CaO and SiO_2)	Blast-furnace slag cement raw material Portland cement mixed material Mineral admixture for concrete Cement clinker raw material (alternative to clay) Earthwork material and ground improvement material (backfill, soil covering, embankment, roadbed improvement, ground drainage layer, etc.) Concrete fine aggregate Calcium silicate fertilizer Soil amendments
Steelmaking slag	Converter and electric arc furnace slag	Hardness and abrasion resistance Hydraulic property Large angle of shear resistance FeO, CaO and SiO_2 content Free from alkali-silica reaction Fertilizer component (CaO, SiO_2, MgO and FeO) Absorption of sulfuric ions and phosphorate ions Fe supply	Asphalt concrete aggregate Block and artificial stone aggregate (steel slag hydrated matrix, steel slag carbonated matrix) Base course material Soil stabilizer (Calcia-modified soil) Earthwork material and ground improvement material Cement clinker raw material Concrete fine and coarse aggregate (electric arc furnace oxidizing slag aggregate) Fertilizer and soil amendments Environmental improvement material (bottom sediment) Iron content supply unit for seaweed bed creation

* Alkali-silica reaction: A reaction between the alkali in cement and the aggregate causing the aggregate to expand, thereby leading to cracks in concrete structures and their collapse.

III Supply and Demand for Iron and Steel Slag

1 Outline of the Supply and Demand for Iron and Steel Slag

In recent years, the annual production of iron and steel slag has been around 35 million tons, and the cumulative external sales volume over the past 40 years has reached approximately 1.25 billion tons. The production of iron and steel slag is linked to steel production. In addition to the slowdown of the global economy since the second half of 2019, the impact of the COVID-19 pandemic in 2020 caused a sharp decline in steel production, resulting in a significant reduction in iron and steel slag production as well. Since then, with the recovery of economic activities, steel production has shown a gradual recovery trend, and as a result, iron and steel slag production has been on an upward trajectory.

During the period of rapid economic growth, large quantities of iron and steel slag were used as construction materials in civil engineering projects related to steelworks. Additionally, its use as a base course material for general roads also began during this time. Ever since the second oil crisis, iron and steel slag have been used in a variety of products for a wide range of applications, responding to the needs for resource and energy savings as well as environmental preservation. For example, iron and steel slag aggregate is expected to serve as an alternative material to natural aggregate due to the reduction in natural materials as a result of the regulation of sea sand extraction in the Seto Inland Sea and other regulations. Taking advantage of the fact that steelmaking slag has a larger angle of shear resistance than natural sand, a seabed improvement method using steelmaking slag as a material for sand compaction piles has been developed, and a wealth of construction experience has been accumulated.

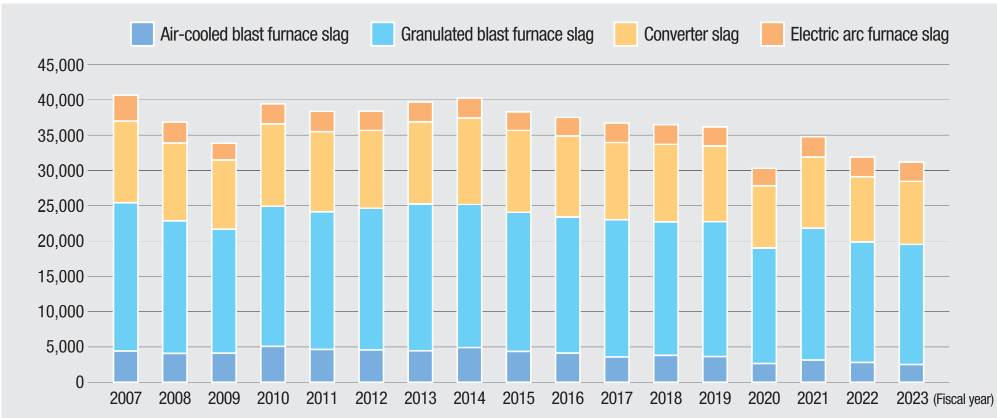
Highly evaluated for its energy-saving effect, which reduces production energy in the calcination process of cement production by 40% or more, and for its CO_2 emission reduction effect, blast-furnace slag cement, consisting of a mixture of ground granulated blast furnace slag and Portland cement, was selected as a designated procurement item under the Act on Promoting Green Procurement in 2001. The expanded use of mixed cements, which includes blast-furnace slag cement, has been incorporated as part of the greenhouse gas reduction target for FY 2030 (a 46.0% reduction compared to FY 2013). Furthermore, many types of blast-furnace slag cement with an increased ratio of blast furnace slag in the cement have recently been proposed to help reduce carbonization.

Additionally, in response to the increasing demand for cement raw materials abroad, the export of granulated slag for cement use has also expanded.

In recent years, steelmaking slag has been recognized as a soil-conditioning fertilizer because it contains micronutrients required by crops, including alkali content, silica (SiO_2), magnesia (MgO), phosphorus (P_2O_5), iron, and manganese (MnO). Furthermore, research has shown that these mineral components are effective in restoring marine environments, and steelmaking slag is expected to see increased demand as an environmental material.

Trends in the Production of Various Types of Iron and Steel Slag

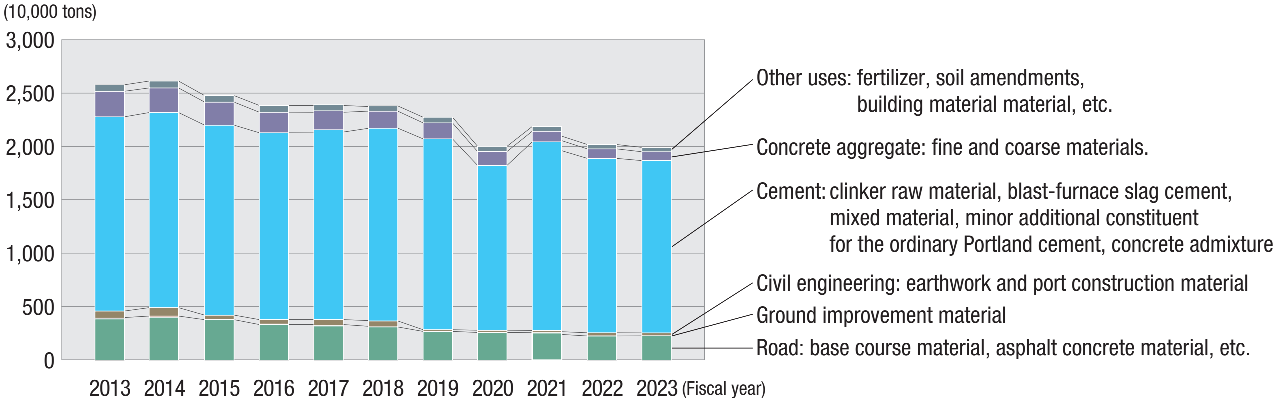
(Unit: 1,000 tons)



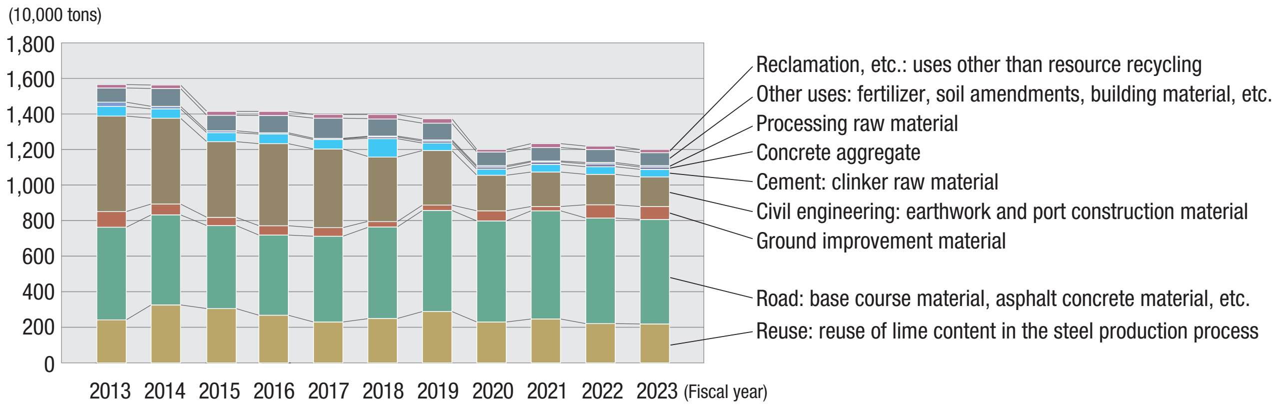
2 Data Collection

Trends in the Use of Blast Furnace Slag and Steelmaking Slag by Usage Breakdown

Trend in the Use of Blast Furnace Slag by Usage Breakdown

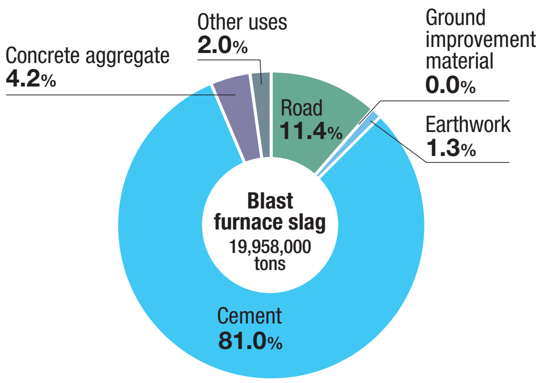


Trends in the Use of Steelmaking Slag by Usage Breakdown

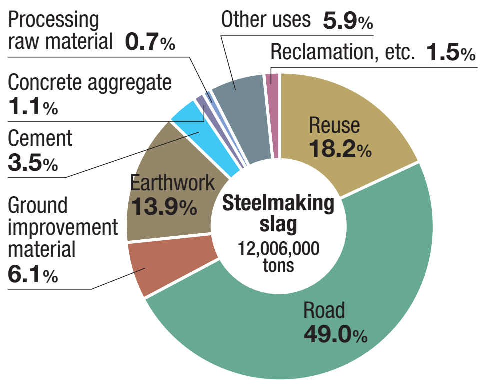


Breakdown of the Usage of Blast Furnace Slag and Steelmaking Slag by Application (FY 2023)

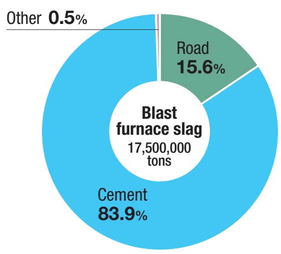
Breakdown of the Usage of Blast Furnace Slag



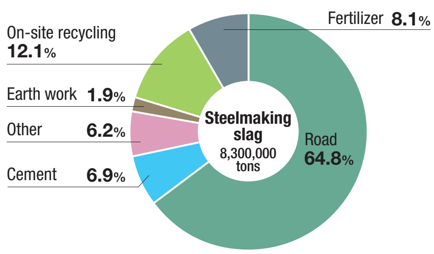
Breakdown of the Usage of Steelmaking Slag



[Reference] Utilization of Blast Furnace Slag and Steelmaking Slag in Europe (2018)



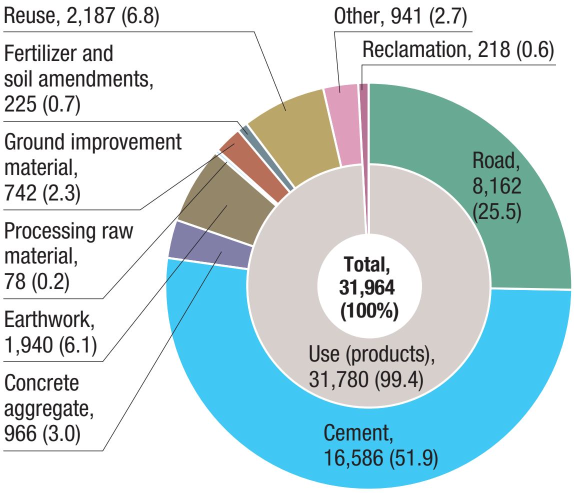
Total for 18 EU countries



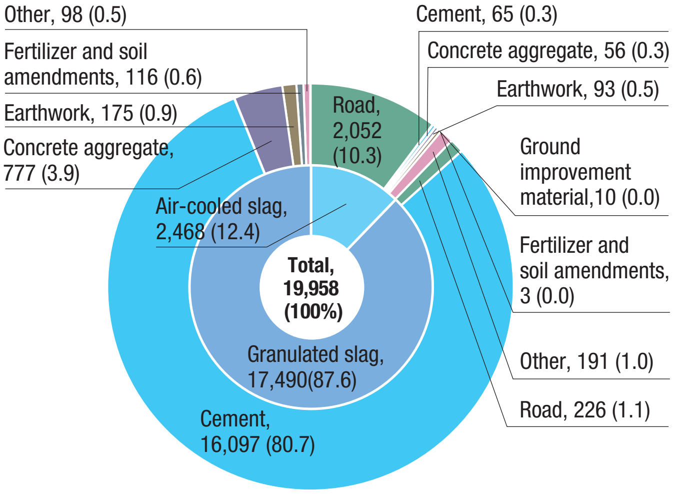
Total for 18 EU countries

Amount of Iron and Steel Slag Used by Application (Actual Results for FY 2023)

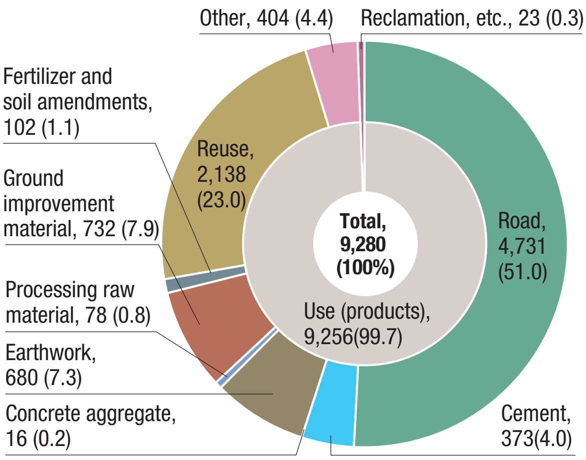
(Unit: 1,000 tons (%))



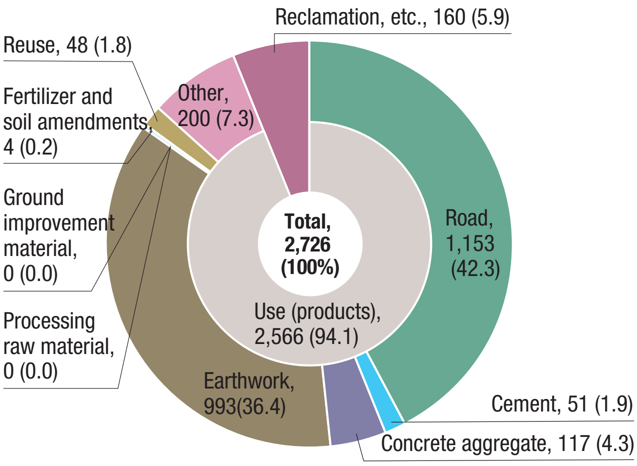
Total Amount Used by Application



Amount of Blast Furnace Slag Used by Application

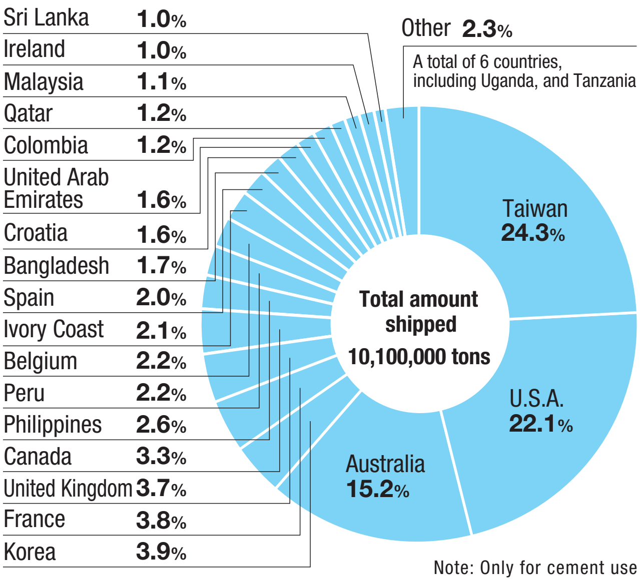


Amount of Converter Slag Used by Application



Amount of Electric Arc Furnace Slag Used by Application

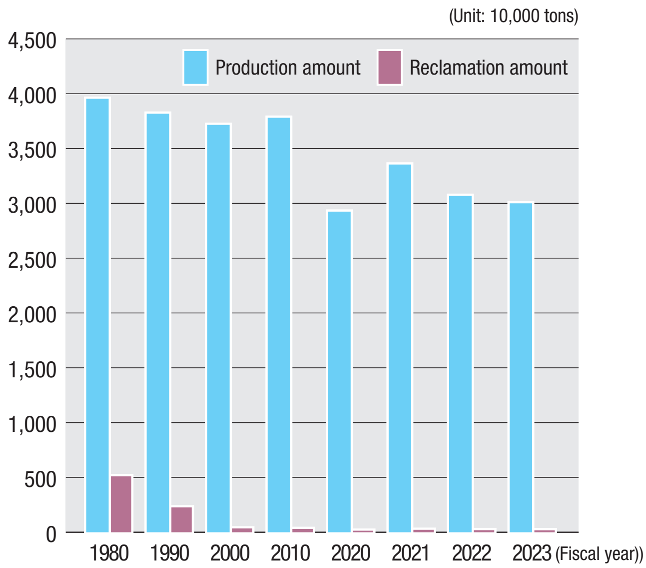
Breakdown of Export Destination of Blast Furnace Slag for Cement Use (FY 2023)



Note: Only for cement use

Trend in Production and Reclamation Amounts of Iron and Steel Slag

(Unit: 10,000 tons)



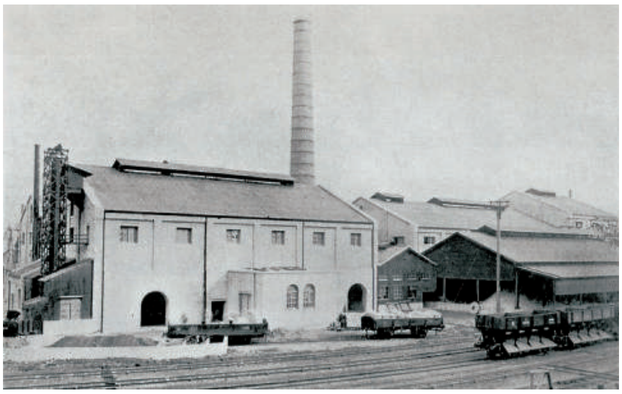
IV History of Iron and Steel Slag Use and the Changing Market Environment

1 From 1910: Commencement of Blast-Furnace Slag Cement Production

Steel products have been produced as essential materials supporting social infrastructure. Iron and steel slag, which is a by-product of steel production, has been effectively utilized through years of research. Today, iron and steel slag is being used in various fields as a valuable material. Below is an overview of the history of the use of iron and steel slag in Japan.

Japan has a long history of recycling iron and steel slag, spanning nearly 100 years. Following the start of integrated steelmaking at the government-operated Yawata Steel Works in 1901, the production of slag bricks began in 1907 by mixing hydrated lime with granulated slag. The test production of blast-furnace slag cement started in 1910, and full-scale production began in 1913. Initially, most of the blast-furnace slag cement was used for construction projects within the steelworks. In 1926, the Japanese Engineering Standards for blast-furnace slag cement (JES No. 29) were established.

Blast-furnace slag cement factory in the early Showa Period



Steelworks

2 The High Economic Growth Period: Iron and Steel Slag as Reclamation and Land Development Materials

During the high economic growth period of the 1960s, steel production increased dramatically, and iron and steel slag was used in large quantities for land reclamation to expand existing steelworks and for the construction of a series of new coastal steelworks. During this period, know-how for the effective use of iron and steel slag as a material for civil engineering works was accumulated. Additionally, the use of iron and steel slag as a base course material for general roads began during this period.

3 After the Oil Crisis: Ongoing Technological Development for Resource Recycling of Iron and Steel Slag

In the first half of the 1970s, when crude steel production exceeded 100 million tons, the need for recycling the large quantities of iron and steel slag became evident. Recognizing the recycling of iron and steel slag as a critical business challenge, steel companies began technological development for iron and steel slag products and activities to develop markets for them. Steel companies worked to establish a system to guarantee the qualitative and quantitative stability of iron and teel slag products, treating slag not as “waste,” but as “a new category of products.”

After the oil crisis in 1973, the recycling of iron and steel slag progressed significantly as social awareness of the importance of energy and resource saving grew.

Systematic resource recycling activities in the steel industry advanced to a new stage by the dissolution of the “Japan Slag Association,” which was primarily composed of sales companies, and the establishment of the “Nippon Slag Association” in 1978, bringing together steel companies to work on public recognition activities, including standardization under the JIS system. Recently, the association’s activities have been strengthened in collaboration with the Japan Iron and Steel Federation to expand the use of iron and steel slag in port and marine applications, as well as in environmental areas.

In the course of establishing a system to promote the recycling of iron and steel slag, steel companies have worked to enhance their quality, develop utilization technologies, and ensure a stable supply, positioning them as high value-added industrial products that leverage their superior characteristics as opposed to merely using slag products as substitutes for natural resources. Thanks to the technologies and trust cultivated over the past 100 years, iron and steel slag is now used in a wide range of applications—including materials for cement, roads, civil engineering works, port construction, and concrete aggregate—and plays an important role in enhancing social infrastructure. Furthermore, even today, when 99% of all iron and steel slag produced is being recycled, efforts are actively being made to develop new utilization technologies and improve production techniques in order to respond to changes in the social environment.

Chubu Centrair International Airport (Aichi Prefecture)

4 Responding to Environmental Changes: Striving for Further Advancements in Iron and Steel Slag

Iron and steel slag products are primarily used in the construction sector as raw materials for cement and road construction materials. However, with the maturation of the economy in Japan, construction demand has been stagnating for many years. Considering the future decline in the working-age population and the entry of competing materials into the construction market, the sales environment for iron and steel slag products has become extremely challenging, with no expectation of demand growth.

On the other hand, looking at the world, there have been significant movements related to the environment that can be seen as a turning point in this era.

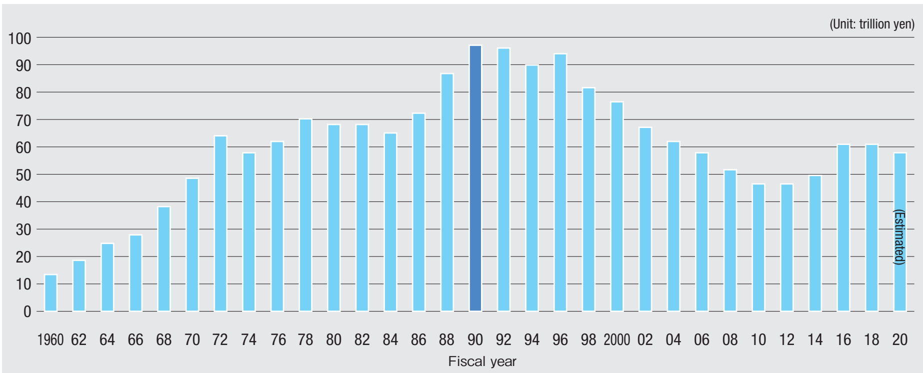
At the United Nations Summit in September 2015, the “2030 Agenda for Sustainable Development” was adopted, setting 17 Sustainable Development Goals (SDGs) and 169 targets to be achieved by 2030. Goal 12, “Ensure sustainable consumption and production patterns,” calls for the use of resources with lower environmental impact, focusing on sustainable production and consumption, and minimizing waste. This goal addresses the depletion of finite natural resources and the indirect increase in environmental impact caused by resource utilization. In Japan, the SDGs Promotion Headquarters, led by the Prime Minister, has been established, with the “development of a circular society” identified as one of its priority issues. This presents an additional opportunity to recognize the value of iron and steel slag products, which are produced and processed using iron and steel slag, a by-product, as a raw material.

Additionally, in addressing the climate change issue, Japan has set a long-term goal of achieving net-zero greenhouse gas emissions by 2050. Furthermore, in the Cabinet decision made in October 2021, a target of a 46% reduction in emissions compared to FY 2013 was established as part of the “2030 Greenhouse Gas Reduction Target” plan. These efforts are related to iron and steel slag products. To promote the use of blast-furnace slag cement, the Ministry of Economy, Trade and Industry has examined “Measures to Promote and Expand the Use of Blended Cement.” Additionally, the “Expanded Use of Mixed Cement” was incorporated as one of the measures in the “Global Warming Countermeasures Plan,” which was adopted in the Cabinet decision in May 2016.

In Japan, the concept of recycling resources was introduced with the enactment of the “Basic Act on Establishing a Sound Material-Cycle Society” in 2000, which spurred efforts toward realizing a recycling-oriented society. Additionally, under the “Act on the Promotion of the Effective Utilization of Resources,” also enacted in 2000, the steel industry was selected as a Specific Resources-Saving Industry, requiring further utilization of iron and steel slag. The steel industry has worked to standardize iron and steel slag products and develop user manuals. Additionally, in the “Act on the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities” (Act on Promoting Green Procurement) enacted in 2001, many iron and steel slag related products are selected as designated procurement items (products contributing to the reduction in environmental impact) in public projects, thereby promoting the use of iron and steel slag products.

In the future, efforts will be needed to further strengthen existing initiatives and enhance the value of iron and steel slag products through more comprehensive approaches, such as promoting the international use of these products in line with global market trends, and contributing to CO_2 absorption through the development of blue carbon ecosystems.

Trend in Japanese Construction Investment



*The real value was calculated from the Construction Coost Deflators (FY 2015 base).
Source: The Ministry of Land, Infrastructure, Transport and Tourism

V Iron and Steel Slag as an Environmentally Friendly Material

1 Contribution to Resource and Energy Saving as well as CO_2 Emission Reduction

Amid growing awareness of environmental issues, iron and steel slag products are highly valued as materials that reduce environmental impact, particularly from the perspectives of resource conservation, energy savings, and CO_2 reduction.

For example, compared to ordinary Portland cement, blast-furnace slag cement containing 45% granulated blast furnace slag offers four key advantages in terms of reducing environmental impact.

(1) The use of ordinary Portland cement is reduced by an amount equivalent to the granulated blast furnace slag content, resulting in approximately 40% savings in limestone, which contributes to resource saving and environmental preservation.

(2) Granulated blast furnace slag, which does not require the calcination process, can reduce coal and electricity consumption by approximately 40% during cement production, thereby enhancing the energy saving effect.

(3) Due to its lower consumption of limestone and energy, blast-furnace slag cement can reduce CO_2 emissions by approximately 320 kg per ton of cement, resulting in a reduction of about 3.2 million tons of CO_2 per year for the production of 10 million tons of blast-furnace slag cement.

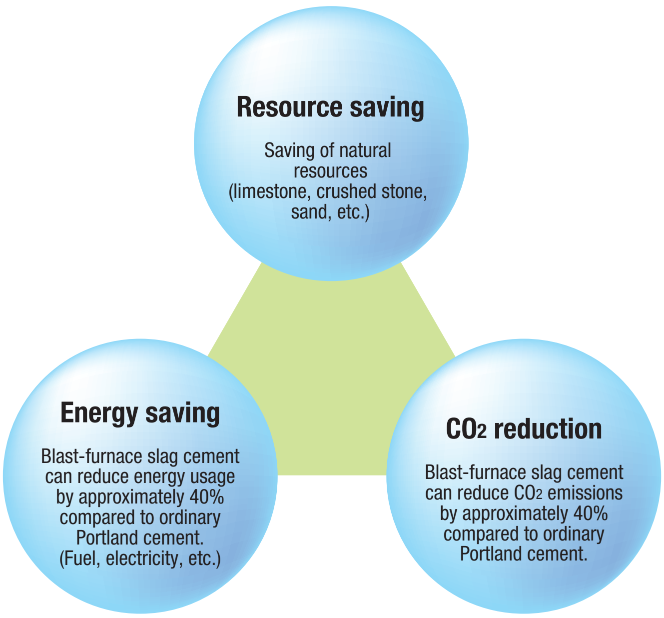
(4) Blast-furnace slag cement excels in chemical resistance, with a low chloride ion diffusion coefficient and permeability coefficient, and also has an alkali-aggregate reaction suppressing effect, making it suitable for constructing durable structures.

Utilizing iron and steel slag as an alternative to natural resources can contribute to environmental conservation by saving natural resources and reducing energy consumption during extraction. In fact, extracting natural rocks and sand consumes large amounts of energy and emits CO_2 through the heavy machinery used to excavate mountains, sea beds, and riverbeds, leading to significant environmental issues such as the destruction of ecosystems and natural habitats.

Iron and steel slag products are already recognized as materials that contribute to environmental preservation, and many of these products have been selected as designated procurement items under the Act on Promoting Green Procurement for public projects.

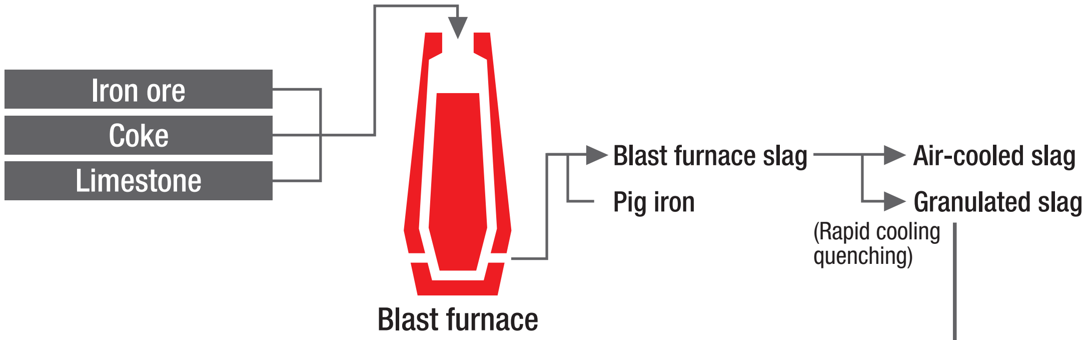
Green procurement refers to an initiative aimed at promoting environmental considerations in procured goods, which was initiated by the United Nations and public organizations in various countries. In Japan, the "Act on the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities" (Act on Promoting Green Procurement) was enacted in April 2001. The government and independent administrative institutions are required to engage in green procurement, and local governments are also expected to promote the procurement of environmentally friendly goods. Furthermore, for companies, the requirements of the ISO 14001 environmental management system include green procurement, thereby encouraging organizations certified with ISO 14001 to promote green procurement.

Characteristics of "Resource and Energy Saving as well as CO_2 Emission Reduction"

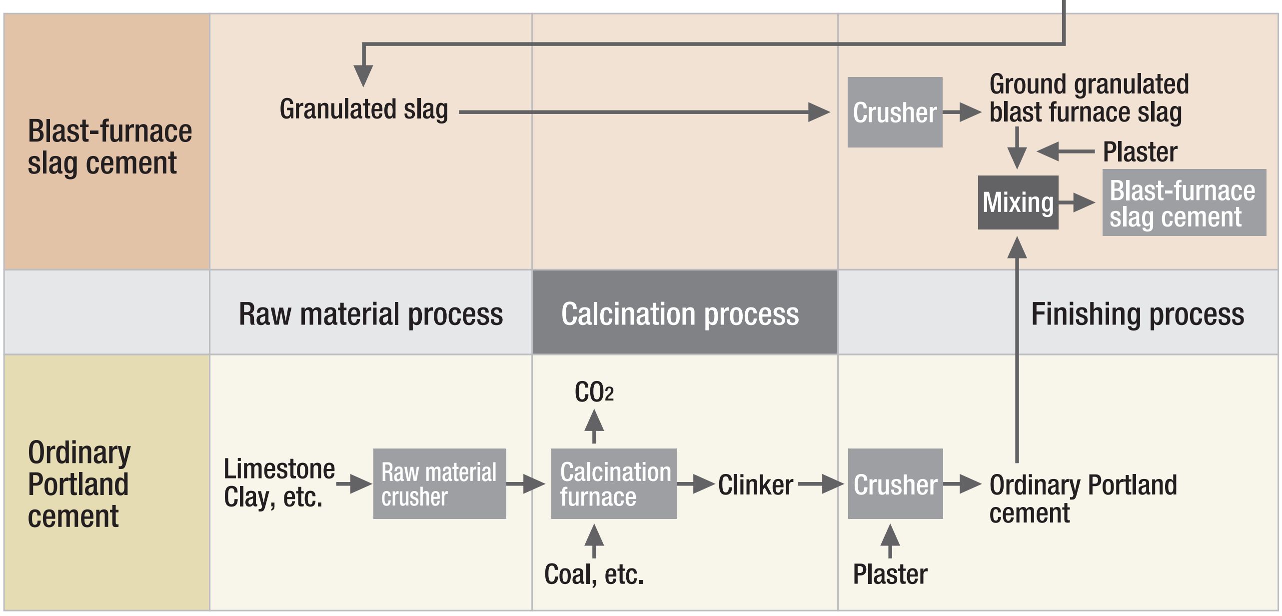


This estimation is based on a 45% ratio of blast furnace slag in blast-furnace slag cement.

Comparison of Production Processes and CO_2 Emissions Between Blast-Furnace Slag Cement and Ordinary Portland Cement



Comparison of Production Processes Between Blast-Furnace Slag Cement and Ordinary Portland Cement



CO_2 Emission Per Ton of Cement (Unit: kg)

CO_2 emission source	Portland cement CO_2 emission (1)	Blast-furnace slag cement Type B CO_2 emission (2)	CO_2 emission reduction (1) – (2)	CO_2 reduction rate (%)
Limestone	476	270	206	43
Electricity and energy	283	170	113	40
Total	759	440	319	42

(Data published by the Japan Cement Association in 2022)

2 Designated Procurement Products under the Act on Promoting Green Procurement

Many iron and steel slag products are highly regarded for their environmental advantages and long track record of use, and have been selected as designated procurement items (products contributing to the reduction of environmental impact) in public works projects under the Act on the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities (commonly known as the Act on Promoting Green Procurement), which came into effect in 2001.

Under the Act on Promoting Green Procurement, the national and local governments are actively promoting procurement, leading to the widespread and effective use of iron and steel slag products as civil engineering materials throughout the country.

Designated procurement items	Condition	Environmental advantage
Blast-furnace slag cement (Designated in FY 2001)	Blast-furnace slag cement containing more than 30% blast furnace slag	• Conservation of limestone resources • Energy saving effect • Reduction in CO_2 emissions
Blast furnace slag aggregate (Designated in FY 2002)	Blast furnace slag aggregate used as a substitute for natural sand (including sea sand and mountain sand), natural gravel, crushed sand, and crushed stone	• Preservation of natural environment • Reductions in fossil fuel consumption and CO_2 emissions during crushing process
Base course material mixed with iron and steel slag (Designated in FY 2002)	Iron and steel slag as base course materials in road construction	• Preservation of natural environment
Asphalt mixture containing iron and steel slag (Designated in FY 2002)	Iron and steel slag aggregate for heated asphalt in road construction	• Preservation of natural environment • Reductions in fossil fuel consumption and CO_2 emissions during crushing process
Granulated slag for civil engineering works (Designated in FY 2003)	Granulated slag for civil engineering works used as a substitute for natural sand (including sea sand and mountain sand), natural gravel, crushed sand, and crushed stone	• Preservation of natural environment • Reductions in fossil fuel consumption and CO_2 emissions during crushing process
Iron and steel slag for ground improvement (Designated in FY 2004)	Steelmaking slag used as a substitute for natural sand (including sea sand and mountain sand) when applying the sand compaction pile method	• Preservation of natural environment • Reductions in fossil fuel consumption and CO_2 emissions during crushing process
Electric arc furnace oxidizing slag aggregate for concrete (Designated in FY 2005)	Electric arc furnace oxidizing slag aggregate used as a substitute for natural sand (including sea sand and mountain sand), natural gravel, crushed sand, and crushed stone	• Preservation of natural environment • Reductions in fossil fuel consumption and CO_2 emissions during aggregate transportation and heavyweight concrete work
Iron and steel slag block (Designated in FY 2008)	Blocks and stone materials made of hydrated matrix, using steelmaking slag as aggregate at a weight ratio of 50% or more and ground granulated blast furnace slag as a binder	• Preservation of natural environment and conservation of limestone resources • Reduction in CO_2 emissions during concrete production • Good biofouling properties when used in marine environments

VI Iron and Steel Slag as an Environmental Material Trusted by Society

1 Conformity with Environmental Standards

① Quality of Iron and Steel Slag Products for Environmental Safety

In 1979, a JIS standard for road focusing on the physical properties of iron and steel slag for road use was established. Since then, various product standards for use as civil engineering materials have been developed, and iron and steel slag products have been used in a wide range of civil engineering applications. The standardization of environmental safety and quality took much longer, but following the establishment of the Test Methods for Chemicals in Slags (JIS K 0058-1 and -2) in 2005 as official environmental safety and quality test methods, the Nippon Slag Association has been working to incorporate environmental safety and quality requirements into the JIS standards for iron and steel slag products. The environmental safety and quality of iron and steel slag products are defined to ensure that soil, groundwater, seawater, and other environmental media in the exposure environment during product use meet relevant environmental standards.

The environmental safety and quality requirements were incorporated into the JIS standards "Iron and steel slag for road construction (JIS A 5015)" and "Slag aggregate for concrete (JIS A 5011-1 and -4)" in the 2013 revision. Furthermore, the January 2015 revision of the "Guidelines for the Management of Iron and Steel Slag Products" clarified and organized the applicable environmental safety and quality requirements according to use locations and purposes.

Environmental Safety and Quality Standards in Iron and Steel Slag for Road Construction (JIS A 5015)

Item	Elusion amount mg/L	Content a) mg/kg
Cadmium	0.01 or less	150 or less
Lead	0.01 or less	150 or less
Hexavalent chromium	0.05 or less	250 or less
Arsenic	0.01 or less	150 or less
Mercury	0.0005 or less	15 or less
Selenium	0.01 or less	150 or less
Fluorine	0.8 or less	4,000 or less
Boron	1 or less	4,000 or less

Environmental Safety and Quality Standards for Slag Aggregate for Concrete (JIS A 5011-1 and -4)

General use

Item	Elusion amount mg/L	Content a) mg/kg
Cadmium	0.01 or less	150 or less
Lead	0.01 or less	150 or less
Hexavalent chromium	0.05 or less	250 or less
Arsenic	0.01 or less	150 or less
Mercury	0.0005 or less	15 or less
Selenium	0.01 or less	150 or less
Fluorine	0.8 or less	4,000 or less
Boron	1 or less	4,000 or less

Port use

Item	Elusion amount mg/L
Cadmium	0.03 or less
Lead	0.03 or less
Hexavalent chromium	0.15 or less
Arsenic	0.03 or less
Mercury	0.0015 or less
Selenium	0.03 or less
Fluorine	15 or less
Boron	20 or less

Note a): It should be noted that the term "content" as used here differs from the general meaning of "total content."

② Environmental Safety and Quality Requirements According to Use Locations and Purposes

Iron and steel slag products used on land are classified into seven categories: roads and railways, concrete aggregates, ground improvement materials, civil engineering and onshore construction, hydrated matrix, fertilizer raw materials, and other. The applicable environmental safety and quality test methods, evaluation criteria, and testing frequency are specified based on factors such as whether the product conforms to JIS standards or equivalent specifications, and whether its use can be distinguished from soil. On the other hand, iron and steel slag products used in port and marine areas are classified into four categories: concrete aggregates, ground improvement materials, port and marine construction, and hydrated matrix. The applicable environmental safety and quality test methods, evaluation criteria, and testing frequency are specified based on factors such as whether the product conforms to JIS standards or equivalent specifications, and whether its use is subject to the elution standards for port use or the environmental quality and quality standards for marine sediments.

Example of Elution Test Results for Iron and Steel Slag Products Using the Test Methods for Chemicals in Slags (JIS K 0058-1)

(Unit: mg/L)

Item	(Reference standards) Environmental quality standards for soil	Blast furnace slag product		Steelmaking slag product	
		Air-cooled slag	Granulated slag	Converter slag	Electric arc furnace slag
Cadmium	0.003 or less	< 0.001	< 0.001	< 0.001	< 0.001
Lead	0.01 or less	< 0.001	< 0.001	< 0.001	< 0.001
Hexavalentchromium	0.05 or less	< 0.02	< 0.02	< 0.02	< 0.02
Arsenic	0.01 or less	< 0.001	< 0.001	< 0.001	< 0.001
Mercury	0.0005 or less	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Selenium	0.01 or less	0.001	< 0.001	< 0.001	< 0.001
Fluorine	0.8 or less	0.2	0.1	< 0.1	< 0.1
Boron	1 or less	< 0.1	< 0.1	< 0.1	< 0.1

Note: The less than symbol (<) indicates a value below the lower limit of quantification.

Example of Elution Test Results for Iron and Steel Slag Products Using the Environmental Quality Standards for Soil (Ministry of the Environment Notification No. 46)

(Unit: mg/L)

Item	Environmental quality standards for soil	Blast furnace slag product		Steelmaking slag product	
		Air-cooled slag	Granulated slag	Converter slag	Electric arc furnace slag
Cadmium	0.003 or less	< 0.005	< 0.005	< 0.005	< 0.005
Lead	0.01 or less	< 0.001	< 0.001	< 0.001	< 0.005
Hexavalent chromium	0.05 or less	< 0.01	< 0.01	< 0.01	< 0.02
Arsenic	0.01 or less	< 0.001	< 0.001	< 0.001	< 0.005
Mercury	0.0005 or less	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Selenium	0.01 or less	0.004	< 0.002	< 0.002	< 0.005
Fluorine	0.8 or less	0.26	0.16	0.62	0.32
Boron	1 or less	0.12	0.10	0.02	0.3

Note: The less than symbol (<) indicates a value below the lower limit of quantification.

Example of Elution Test Results for Iron and Steel Slag Products Using the Environmental Quality Standards for Marine Sediments (Ministry of the Environment Notification No. 14)

(Unit: mg/L)

Item	Determination criteria concerning marine sediments	Blast furnace slag product		Steelmaking slag product	
		Air-cooled slag	Granulated slag	Converter slag	Electric arc furnace slag
Mercury or its compounds	0.005 or less	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Cadmium or its compounds	0.1 or less	< 0.001	< 0.001	< 0.001	< 0.001
Lead or its compounds	0.1 or less	< 0.05	< 0.05	< 0.05	< 0.005
Hexavalent chromium or its compounds	0.5 or less	< 0.4	< 0.4	< 0.4	< 0.01
Arsenic or its compounds	0.1 or less	< 0.005	< 0.005	< 0.005	< 0.002
Fluoride	15 or less	0.3	0.26	0 ~ 4.4	< 0.2
Selenium or its compounds	0.1 or less	< 0.1	< 0.1	< 0.1	< 0.002

Note: The less than symbol (<) indicates a value below the lower limit of quantification.

2 Quality Control from Production to Customer Application

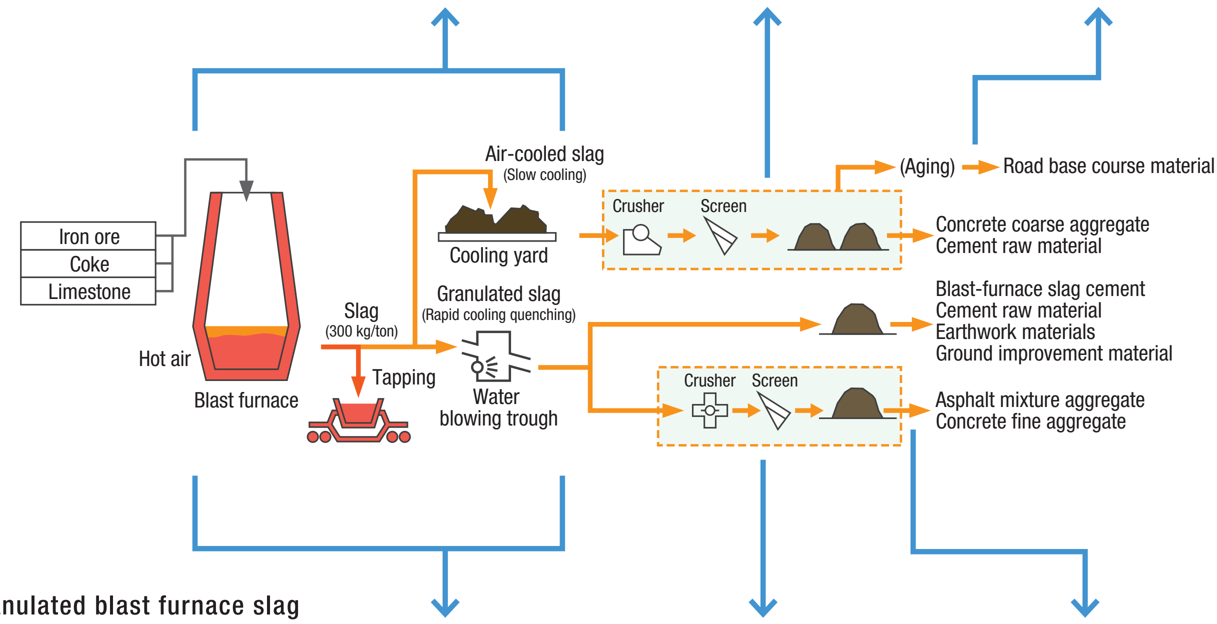
① Production Management of Iron and Steel Slag Products

Steelmaking processes were originally designed to produce pig iron and steel. However, today, the production of high-quality iron and steel slag products is also regarded as an important element in the operation and facility design of steel production. Each steel company takes measures at every stage of the process and implements strict production management to produce iron and steel slag products that meet quality specifications such as JIS standards, according to their intended applications.

Example of Quality Control in the Production Process of Blast Furnace Slag Products (Table)

Air-cooled blast furnace slag

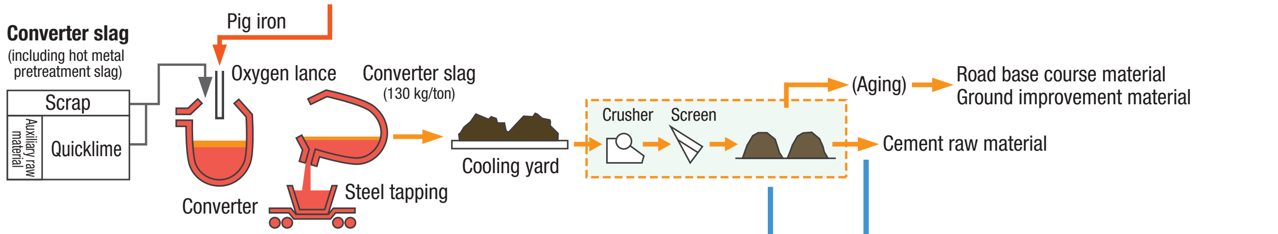
Process	Raw material, dissolution, cooling	Process	Shipping
Quality control method	Raw material mix Dissolved slag temperature Water spraying method	Crushing and classification Aging	Inspection and analysis
Quality control item	Chemical component Porosity	Grading Modified CBR Abrasion value Density in oven-dry condition Bulk density Fineness modulus	Environmental safety and quality Standards by application (Yellow leaching test for blast furnace slag, etc.)



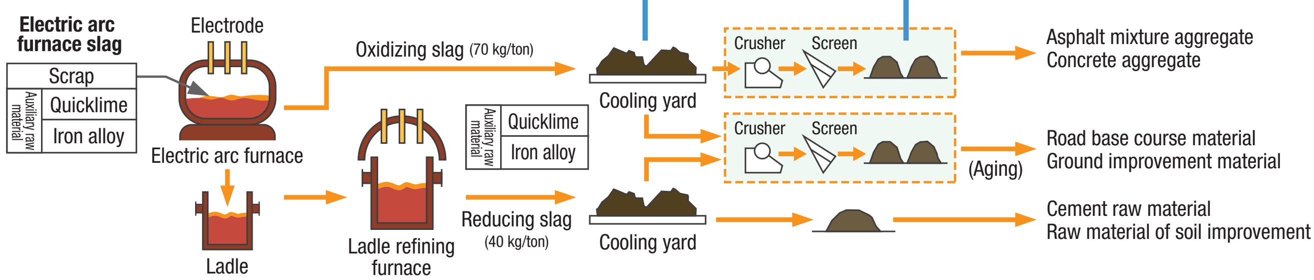
Granulated blast furnace slag

Process	Raw material, dissolution, cooling	Process	Shipping
Quality control method	Raw material mix Dissolved slag temperature Water blowing pressure	Crushing and classification Addition of anti-clumping agent	Inspection and analysis
Quality control item	Chemical component Percentage of glass content Porosity	Grading Density in oven-dry condition Bulk density Fineness modulus	Environmental safety and quality Standards by application (Storage stability test, etc.)

Quality Control in the Production Process of Steelmaking Slag Products



Process	Raw material, dissolution, cooling	Process	Shipping
Quality control method	Selection of scrap Selection of refining conditions • Quicklime usage • Dolomite usage • Amount of refining accelerators used Water spraying method	Crushing and sieving Magnetic sorting Aging	Inspection and analysis
Quality control item	Chemical component Expansion stability Basicity Powdering prevention	Iron content Grading Modified CBR Abrasion value Density in oven-dry condition Bulk density Fineness modulus	Environmental safety and quality Specification according to use (Immersion expansion test, etc.)



3 Management from Shipping to Customer Application

In 2005, the Nippon Slag Association established the "Guidelines for the Management of Iron and Steel Slag Products" (hereinafter referred to as the "Guidelines"), which specify the management items that member companies should implement at each stage of the process, from the production of iron and steel slag to its use by customers. The member companies of the Nippon Slag Association strive to enhance peace of mind and confidence for customers by managing each stage: production, quality inspection, transportation, off-site storage, and use of iron and steel slag products, based on the Guidelines.
Since their establishment in 2005, the Guidelines were revised nine times by 2022, reflecting ongoing efforts to further strengthen the management system.
Each member company of the Nippon Slag Association has developed its own product management manual in compliance with the Guidelines and has established a system to ensure its implementation and control. Additionally, in order to enhance the reliability of iron and steel slag products for society, the Nippon Slag Association has introduced a third-party audit system to review the quality control status at each member company's business establishment, based on their respective product management manuals. The Association also publishes a list of audit results to show that iron and steel slag products are being managed in compliance with the Guidelines.

The Guidelines for the Management of Iron and Steel Slag Products

Table of Contents

1. Purpose
2. Scope of Application
3. Responsibilities of Each Member Company
4. Quality Control of Iron and Steel Slag Products
5. Sales Management of Iron and Steel Slag Products
6. Post-Construction Investigation
7. Responses to Inquiries, Complaints, and Concerns from Administrative Agencies and Local Residents
8. Manual Development, Compliance Status Inspections, and Corrective Actions
9. Report to the Nippon Slag Association
10. Regular Inspections and Maintenance of the Guidelines

(Revised on July 1, 2022 by the Nippon Slag Association)

4 Environmental Measures in the Use of Slag Products

The Guidelines require that, in order to enhance the understanding of customers regarding the potential environmental impacts of improper use, information on the quality characteristics of iron and steel slag products and precautions for their use (such as pH characteristics, dust characteristics, etc.) be provided to end users.

Additionally, the Guidelines require the voluntary determination of the necessity of field surveys before, during, and after construction, based on factors such as the construction volume, construction location, and intended uses of iron and steel slag and implementation of field surveys.

The Precautions for pH Characteristics and Dust Characteristics as Described in the Guidelines

(Excerpt from the Guidelines)

1. pH Characteristics

(1) Precautions

◎ [On-land Use]

- In cases where there is a risk that water in contact with iron and steel slag products may flow out of the site without passing through soil, it is necessary to implement measures such as covering the slag with soil that has a high alkali adsorption capacity or neutralizing the water with carbon dioxide before draining, similar to the use of recycled concrete base course materials or cement-stabilized soil.

◎ [Offshore use]

- There is a possibility that seawater may become cloudy white due to the precipitation of magnesium hydroxide when iron and steel slag products are applied to seawater. Use this product only after confirming that it does not affect the environment through prior examination..

(2) Technical Information

- Due to the influence of lime content, iron and steel slag products cause the pH to increase to 10 to 12.5 when reacted with water and exhibit alkalinity similar to recycled concrete base course materials and cement-stabilized soil.
- As soil in Japan is generally acidic, alkali components leached from iron and steel slag products are absorbed and neutralized by the soil.

2. Dust Characteristics

(1) Precautions

- Among iron and steel slag products, those that are not transported by bulk tank trucks or stored in silos may generate dust depending on the dryness and wind speed. Therefore, measures should be taken to prevent any environmental issues during transportation, storage, and construction using these products.

PRODUCTS

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

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

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 re-inforcing 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 CO_2 Emissions

The Japanese cement industry emits CO_2 equivalent to approximately 4% of the country's total greenhouse gas emissions. Most of this CO_2 is generated during the production of clinker, an intermediate product of cement, through the calcination of limestone. Blast-furnace slag cement can reduce CO_2 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.

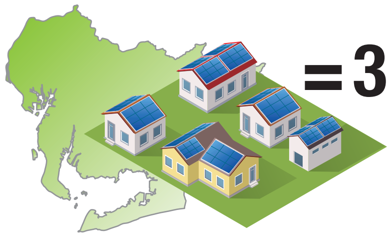
CO_2 Emission Reduction Effect by Blast-Furnace Slag Cement (Compared with Estimated Annual Value)

Annual CO_2 reduction through the production of blast-furnace slag cement: 3.6 million tons

- CO_2 Absorption by Forests (840,000 ha) in Akita Prefecture (840,000 ha)

= 3.42 million tons

- CO_2 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 furnace 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.

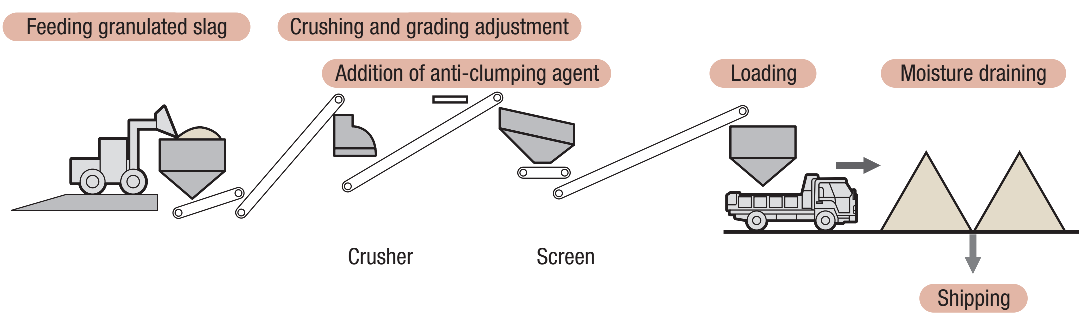
In addition to these advantages, blast furnace slag fine aggregate has recently attracted attention for its ability to suppress the drying shrinkage of concrete and to improve sulfuric acid resistance and freeze-thaw resistance. When combined with appropriate mix design and construction practices, it 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/cm^3, 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 CO_2 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

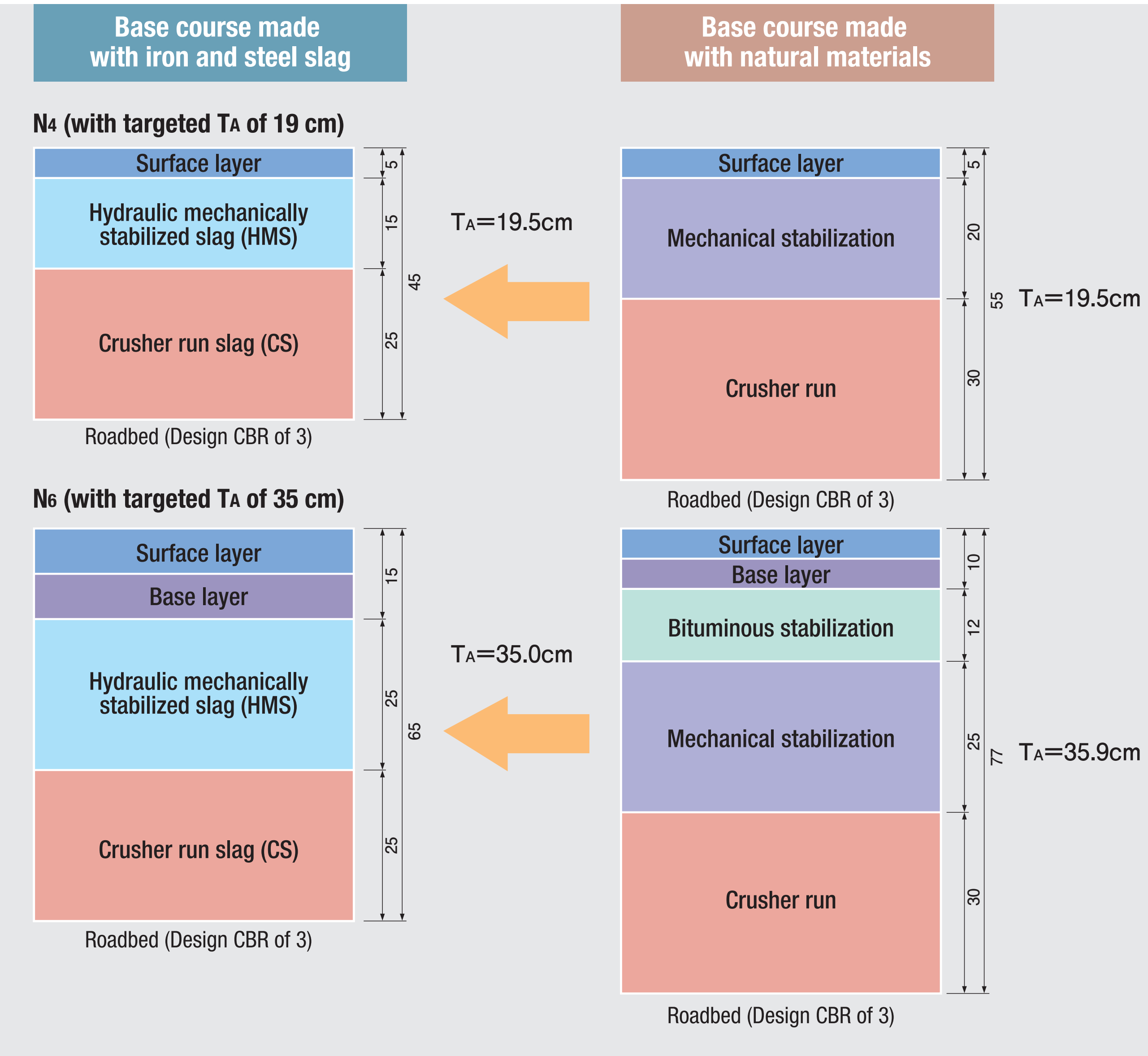
Excellent Durability and Cost-effectiveness

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.

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

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

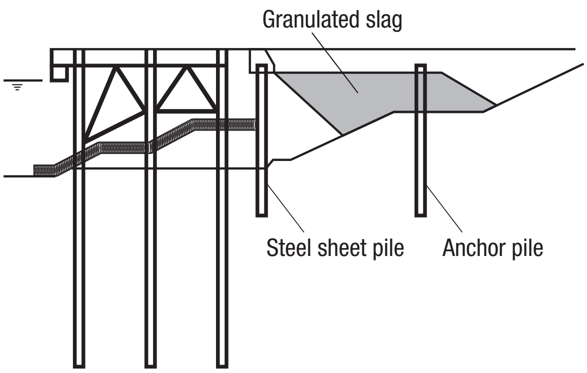
* TEU: A unit indicating the loading capacity of a container ship; 1 TEU is equivalent to one 20-foot container.

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 m^3) 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 m^3) was laid over a 90 cm thick sea sand layer.

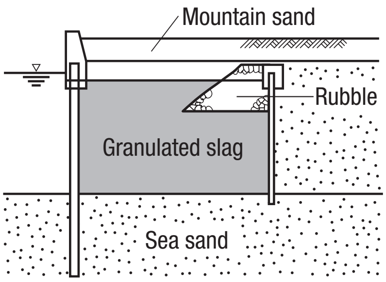
Kitakyushu Airport

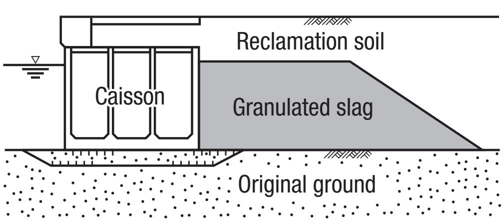
Tobishima Pier in the Port of Nagoya

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.

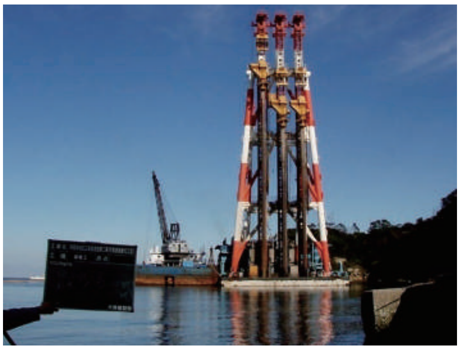
Use of Steelmaking Slag for Liquefaction Countermeasures:
Nabeta Pier Quay Wall in the Port of Nagoya

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])

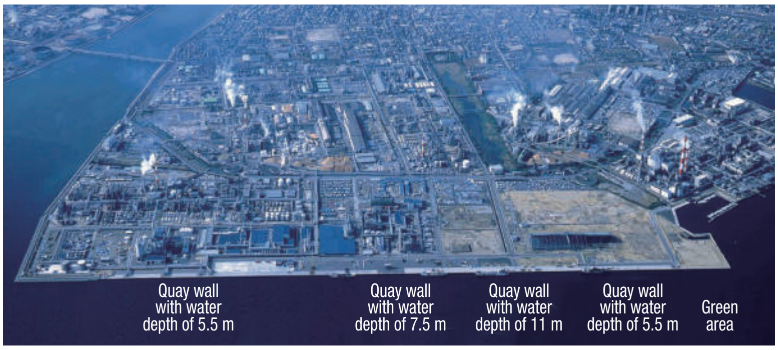
Characteristics of Steelmaking Slag for Ground Improvement

- **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**

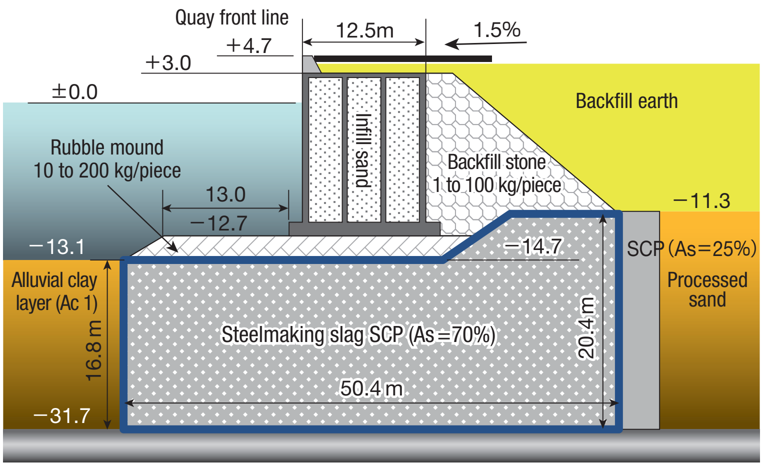
Development of Multi-Purpose International Terminal Quay Wall (–11 m) at the Higashi-Sakae District of Otake Port in Hiroshima Prefecture



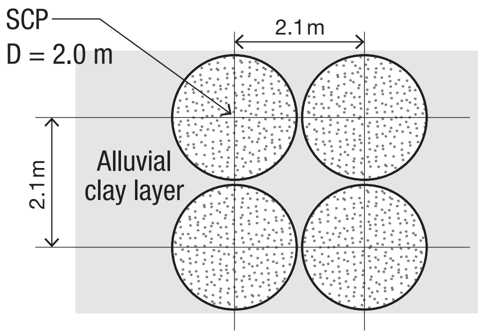
Offshore SCP Installation Work



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



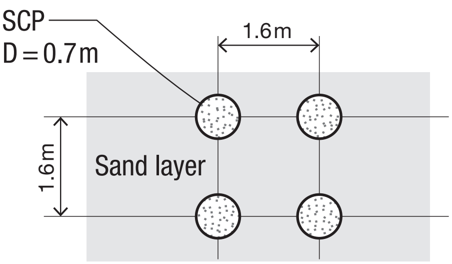
Section of Quay Wall at Higashi-Sakae District in Otake Port



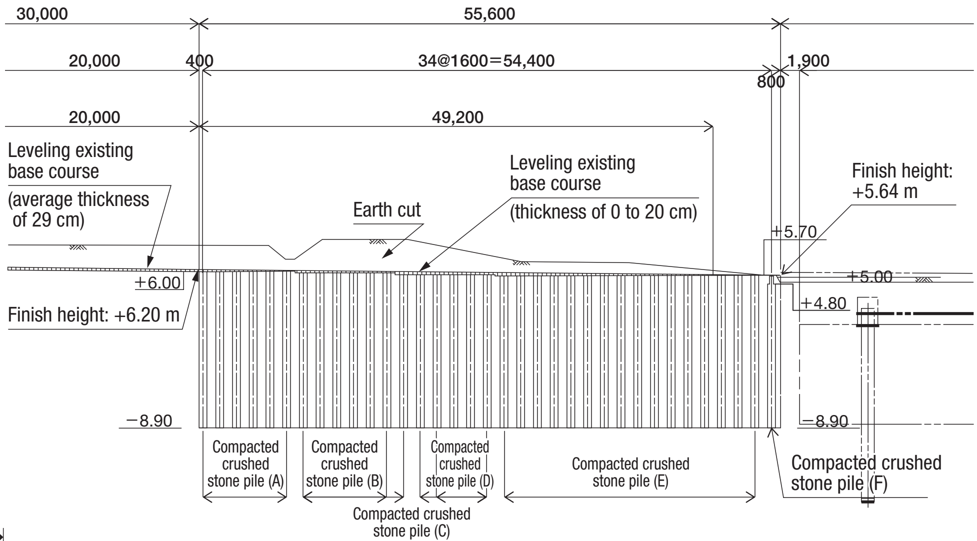
SCP Layout Plan

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

On-land SCP Installation Work



SCP Layout at Nabeta Pier



Example of the Section of Steelmaking Slag SCP

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 phosphorate fertilizer, and byproduct fertilizer. Among the types of iron and steel slag, blast furnace slag contains fertilizer components such as calcia (CaO), silica (SiO_2), and magnesia (MgO). In addition to calcia, silica, and magnesia, steelmaking slag contains iron(II) oxide (FeO), magnesia (MnO), and phosphorus(V) Oxide (P_2O_5).

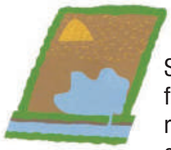
Fertilizers made from blast furnace slag are mainly used for rice cultivation, while those made from steelmaking slag are widely used not only for rice cultivation but also for field crop and pasture cultivation.

● 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**

Silica absorbed by rice: 120 kg

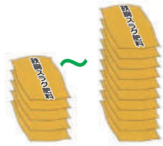
Leached silica: 36 kg



Silica supplied through soil: 5 to 50 kg (sandy soil to cohesive soil)

Silica supplied from 500 kg of rice straw or 1 ton of compost: 50 kg

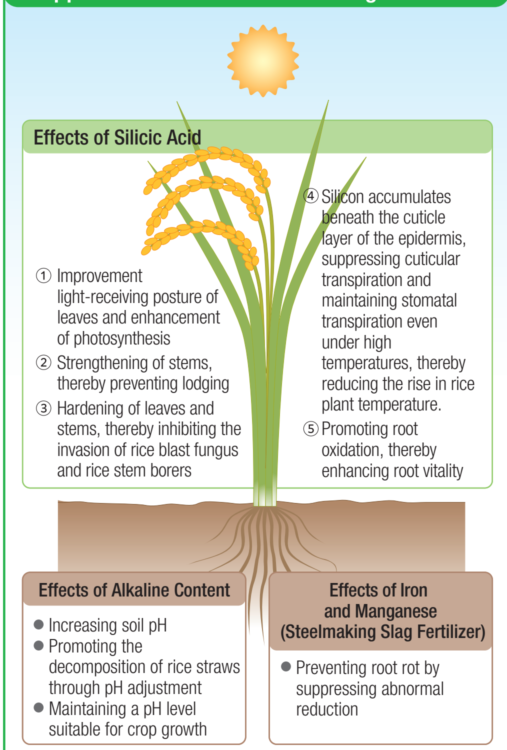
Silica supplied from irrigation water: 28 kg



Silica shortage in terms of steelmaking slag fertilizer: 100 kg (for cohesive soil) to 200 kg (for sandy soil)

Effects on Rice Cultivation

(Blast Furnace Slag Fertilizer and Steelmaking Slag Fertilizer)



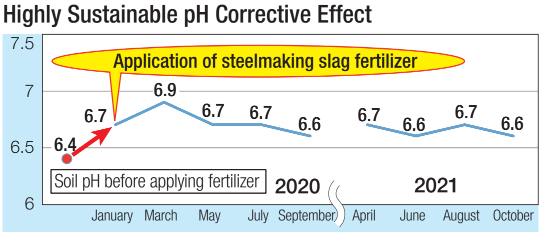
High temperature damage to paddy rice during the ripening period causes significant reductions in both the quality and yield of rice. The importance of soil preparation fertilizers, including slag fertilizers, is currently being re-evaluated.

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



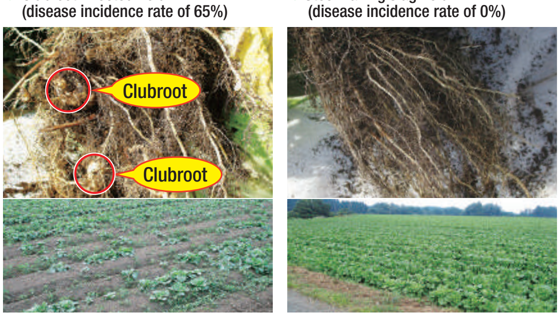
Example of a test in Oita Prefecture where steelmaking slag fertilizer was applied at a rate of 3 tons per 10 acres to a depth of 15 cm.

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.

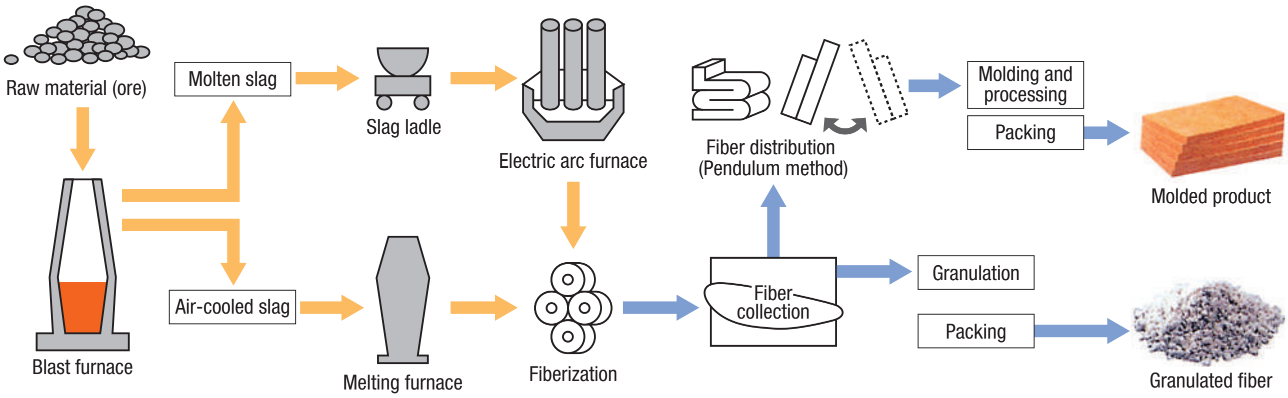
* It is recommended to determine the application rates by consulting with agricultural advisors regarding the soil in question and the pH buffering curves of steelmaking slag fertilizers.

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

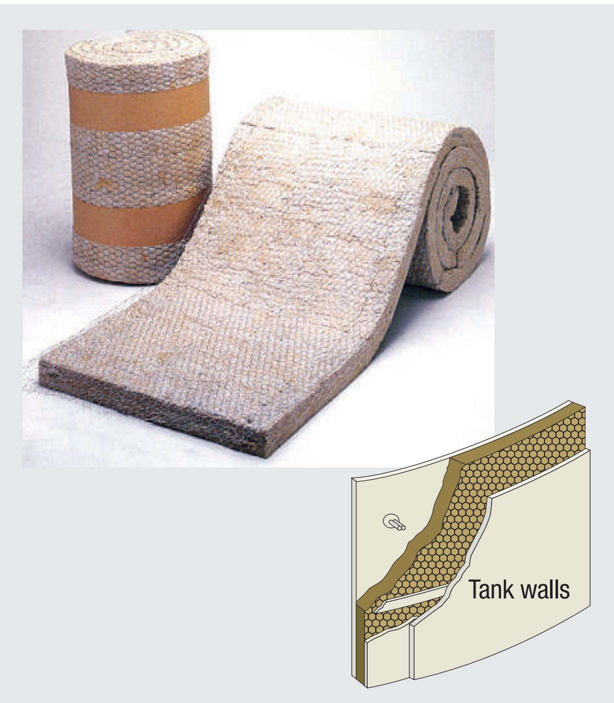
7 Rock Wool

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

II Examples of Iron and Steel Slag Adoption in Large-Scale Projects

1 Tokyo International Airport Runway D Construction and Associated Work

Runway D of Tokyo International Airport, with a length of 2,500 m, was constructed on a new airport island measuring 3,120 m in length, offshore from the existing airport island. The new airport island features a hybrid structure, consisting of a 1,100 m section with a piled pier structure using steel jackets and a 2,020 m reclamation section. Approximately 1.8 million tons of iron and steel slag products, including artificial stone made by steel slag hydrated matrix, were used for partition dikes, liquefaction countermeasure materials, and temporary road materials.

Tokyo International Airport Runway D Construction and Associated Work

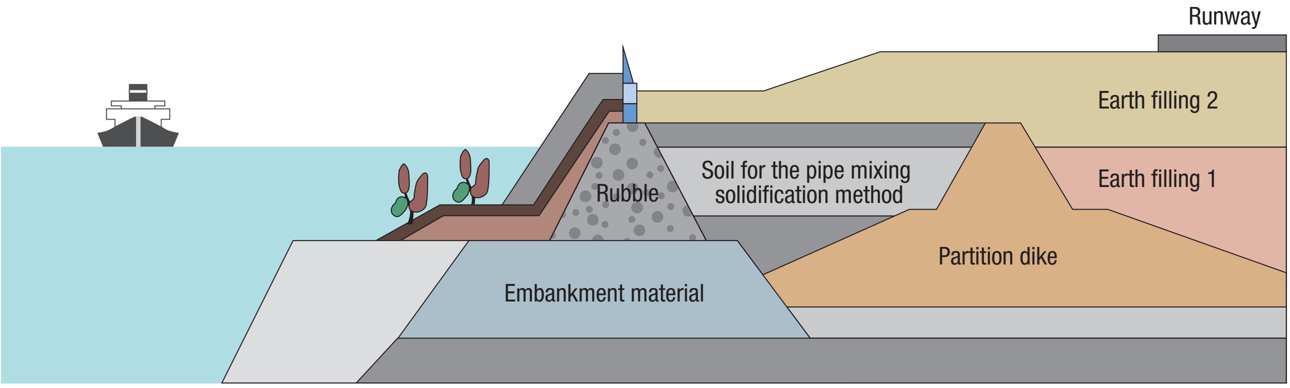
Usage of Iron and Steel Slag Products

(10,000 tons)

	Artificial stone made by steel slag hydrated matrix	Granulated blast furnace slag	Steelmaking slag	Total
Partition dike	23	74		97
Earth filling (for liquefaction prevention)	19			19
Earth filling (for temporary road construction)	60		9	69
Total	102	74	9	185

* In addition to the above, 360,000 tons of blast-furnace slag cement was used as the soil material for the pipe mixing solidification method.

Work Items for Which Iron and Steel Slag Products were Used in Tokyo International Airport Runway D Construction and Associated Work

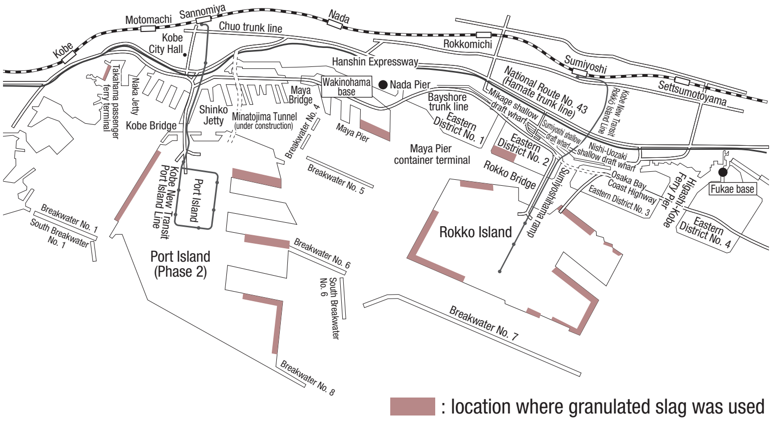


2 Contribution to Earthquake Reconstruction Works

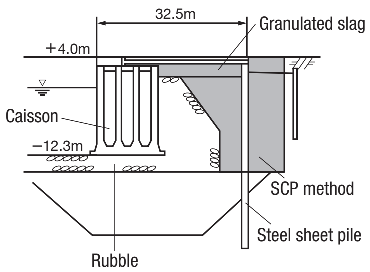
The Great Hanshin-Awaji Earthquake: Rokko Island in Kobe City

Approximately 1.1 million tons of granulated blast furnace slag were used in the Kobe Port quay wall restoration work following the Great Hanshin-Awaji Earthquake in 1995. The quay walls of the Rokko Island District in Kobe Port were severely damaged due to the large displacement of the foundations supporting structures known as caissons. During the restoration, it was necessary to minimize the loads applied to the existing structures. Therefore, to reduce earth pressure, a construction method using granulated blast furnace slag for backfilling was adopted over an area approximately 19 meters wide behind the caissons.

Locations where granulated slag was used in the Kobe Port restoration work



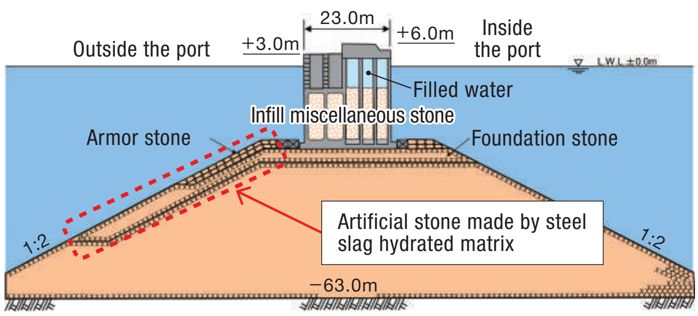
Kobe Port Quay Wall Restoration Work (Rokko Island, Kobe City)



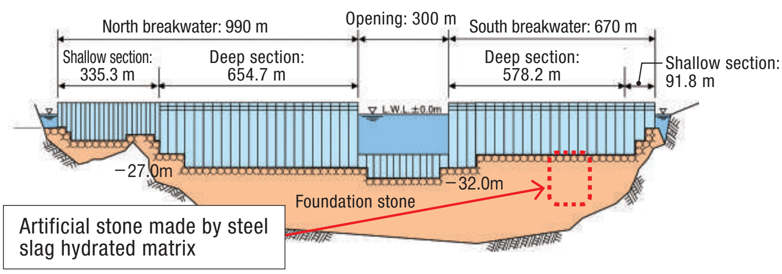
Great East Japan Earthquake: Breakwaters at the Entrance of Kamaishi Bay

Artificial stone made by steel slag hydrated matrix was used for the restoration work of the Breakwater at the Entrance of Kamaishi Bay as armor stone for the mounds of the caisson breakwaters that were damaged in the Great East Japan Earthquake. The restoration of the breakwater at the entrance of the bay covered the 370 m section of the south breakwater (total length 640 m), the 870 m section of the north breakwater (total length 990 m), and the 300 m opening. The work was completed at the end of March 2018, with approximately 200,000 m³ of artificial stone made by steel slag hydrated matrix being used.

Locations Where Artificial Stone Made by steel slag hydrated matrix (Armor Stone) were Used



Elevation of the Breakwater at the Entrance of Kamaishi Bay



3 Examples of Iron and Steel Slag Adoption in Large-Scale Projects

Name	Usage (Unit: m^3)	Application (Type of slag)	Year of construction
Restoration Work for the Great Hanshin-Awaji Earthquake	1,200,000	Reinforcing earthquake resistance of quay walls (granulated slag products)	1996
Kitakyushu Airport	1,380,000	Improving soft ground (sand mat) (granulated slag products)	2000~2002
Chubu Centrair International Airport	1,170,000	Base course material for runway, etc. (granulated slag and steelmaking slag products)	2001~2004
Kobe Airport	900,000	Base course material for runway, etc. (steelmaking slag and granulated slag products)	2003~2004
Kansai International Airport Phase 2 Work	510,000	Base course material for runway, etc. (steelmaking slag and granulated slag products)	2004~2007
Tokyo International Airport Runway D Construction and Associated Work	1,180,000	Partition dike, base course material for temporary road, etc. (artificial stone made by steel slag hydrated matrix, granulated slag products, steelmaking slag products)	2007~2010

4 Other Notable Adoption Examples

Granulated slag products for civil engineering works (100,000 m^3 or more)

Name	Usage (Unit: m^3)	Application (Type of slag)	Year of construction
Shimotsu Port Work	227,000	Covering soil	1998
Mishima, Kawanoe-Kaneko District Work	203,000	Revetment backfill	1998~
Municipal Works in the Southeast Part of Ibaraki Prefecture	296,600	Roadbed, drainage foundation, etc.	2000~2004
Nagoya Port Tobishima Quay Wall No. 2 Work	100,000	Revetment backfill	2006~2007
New Kitakyushu Airport	184,000	Soft ground improvement (sand mat)	2010~2011

Steelmaking slag products for ground improvement (100,000 m^3 or more)

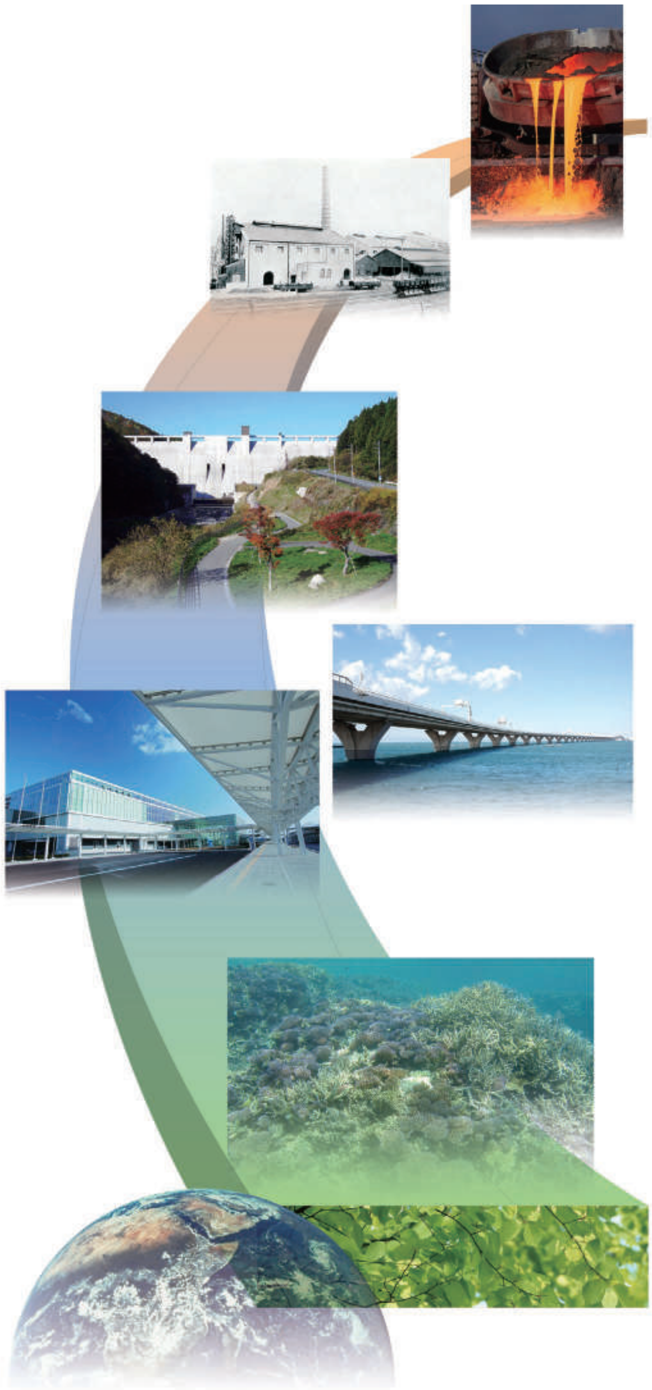
Name	Usage (Unit: m^3)	Application (Type of slag)	Year of construction
Nagoya Port Nabeta Pier West Section No. 5 Work	125,000	SCP	1997~1998
Onomichi-Itozaki Port Kaino District Revetment Work	158,000	SCP	1998~2000
Otake Port Quay Wall Repair Work	146,000	SCP	1998~2000
Kure-City Aga Marinopolis Work	268,000	SCP	1998~2000
Onomichi-Itozaki Port Kaino District Revetment Work	110,000	SCP	1999~2000
Otake Port Higashi-Sakae District Quay Wall Construction Work	242,000	SCP	2001
Otake Port Higashi-Sakae District Quay Wall Construction Work	210,000	SCP	2002
Niihama Port Waste Disposal Site Revetment Construction Work	168,000	SCP	2002
Tokyo Port Lot No. 10 Work	231,000	SCP	2007
Nagasaki Port (Kogakura-Yanagi District) Quay Wall Ground Improvement Work	120,000	SCP	2009
Nabeta Pier in Aichi Prefecture	120,000	SCP	2009~2010
Nagasaki Port Repair Work	342,500	SCP	2009~2011
Breakwater at the Downstream Section of Kitakami River in Miyagi Prefecture	150,000	SCP (on land)	2013~2014
Haneda Airport Offshore Expansion Work	1,366,000	Loading embankment and paving	1985~1993
Daikoku Pier Container Yard in Yokohama Port	205,000	Loading embankment and paving	1990
Yokohama City Daikoku Pier Phase 2 Work	144,000	Loading embankment and paving	1991~1992
Port Island in Kobe City	257,000	Reclamation material	2004~2005
Samukawa Eastern Coast Land Formation Work	370,000	Partition dike	2005~2007
Fukuyama Port Main Waterway District Temporary Road Work	250,000	Temporary road and backfill	2006~2007
Fukuyama Port Main Waterway District	644,800	Embankment	2006~2008

*) The usage was excerpted from the Iron and Steel Slag News (the Nippon Slag Association) in the Handbook for Recycled Products Recommended for Port Works published by the Recycle Report Promotion Council.

FUTURE

I Development of Application Technologies Gaining Attention in the Environmental and Global Era

Iron and Steel Slag: The Environmental Material for the Future



The development of iron and steel slag utilization technologies has been ongoing for about a century, primarily in the fields of cement and road construction. However, with the maturation of the economy and industry and the declining trend in new investments in social infrastructure, it is essential to develop applications and markets for iron and steel slag in order to create stable demand that meets societal needs, ensuring its continued effective use in the future. In addition to furthering the conventional use of iron and steel slag, the Nippon Slag Association is advancing development to realize the various potentials of iron and steel slag, considering the following perspectives as increasingly important.

- Utilizing the environmental restoration effects of iron and steel slag. While the application of iron and steel slag has primarily focused on reclamation in marine areas, future development themes should also include measures to address natural disasters in port areas and the restoration of lost natural marine environments. Research has shown that the iron and mineral components of iron and steel slag are effective in the environmental restoration of marine areas.
- Focusing on the importance of utilizing iron and steel slag to achieve a carbon-neutral society, and maximizing its energy-saving and CO_2 reduction effects. For example, further CO_2 reduction through the use of ground granulated blast furnace slag as a binder, as seen in blast-furnace slag cement, is expected to be one of the key measures for realizing carbon neutrality.
- Pursuing hybrid effects through the combination of various types of iron and steel slag, as well as combining iron and steel slag with other materials. These combinations will generate various advantages that cannot be achieved by individual materials alone, and are expected to be practically applicable across multiple fields.

The expansion of such uses will contribute to further advancing Japan's recycling-oriented society and promoting sustainable development. The Nippon Slag Association and its member companies will actively work to promote and expand the use of iron and steel slag, not only in public works but also in various other projects. This will be achieved with the support of various organizations, including the government, local municipalities, universities, and research institutes, while gaining the understanding of stakeholders. The following introduces recent examples of iron and steel slag utilization technology development.

1 Contribution to Marine Environment Improvement and Restoration: Creating a Rich Marine Environment with Steel

Blocks and Artificial Stone Materials Made by steel slag hydrated matrix (JFE Steel Corporation and Nippon Steel Corporation)

The steel slag hydrated matrixx were developed as an alternative to cement concrete. These recycled products are made by replacing cement with ground granulated blast furnace slag as the binder, and using steelmaking slag in place of natural stone and sand as aggregates, with the optional addition of alkaline activators or admixtures as needed. By using recycled products for nearly all raw materials, the hydrated matrix are expected to reduce CO_2 emissions during cement production and minimize the environmental impact associated with the extraction of natural aggregate.

Steel slag hydrated matrix are essentially produced using the same processes as concrete products. Mixed and poured into formwork using equipment similar to that used in concrete plants, blocks of any shape can be produced. Additionally, by crushing them after curing, hydrated matrix can be processed into stone materials of various sizes. As a result, they have been applied in port construction for wave-dissipating blocks, armor blocks, and as alternative stone materials. The track record of hydrated matrix includes block installation work by the Ministry of Land, Infrastructure, Transport and Tourism, Haneda Runway D construction, revetment restoration work following the Great East Japan Earthquake, and revetment works at various steelworks. The total usage reached over 1.4 million m^3 (as of FY 2016). The artificial stone materials (Frontier Stone® and Frontier Rock®) made by steel slag hydrated matrix have received Verification and Evaluation Report No. 22002 for port-related private technologies from the Coastal Development Institute of Technology and have been selected as designated procurement items under the Act on Promoting Green Procurement. The characteristics of steel slag hydrated matrix are as follows.

(1) Density

The density of artificial stone materials made by Steel Slag Hydrated Matrix ranges from 2.1 to 2.9 t/m^3, depending on the raw materials used and the mix design. Additionally, blocks made by Steel slag hydrated matrix typically have densities of 2.3 to 2.6 t/m^3 in the standard mix design (compared to the density of ordinary Portland concrete, which is approximately 2.3 t/m^3), giving them excellent wave stability.

(2) Mechanical characteristics

Steel Slag hydrated matrix exhibit a 28-day strength of 9.8 N/mm^2 or more, which is equivalent to natural stone categorized as semi-hard stone. With modifications to the mix design, strengths of up to 30 N/mm^2 can be achieved. As a result, they show greater potential for long-term strength development compared to ordinary concrete. In terms of bending and tensile strength, they are comparable to ordinary concrete with the same compressive strength. Additionally, they have a lower abrasion coefficient than ordinary concrete, offering superior wear resistance.

Overview of Blocks and Artificial Stone Materials Made by Steel Slag Hydrated Matrix

Item		Blocks made by steel slag hydrated matrix	Artificial stone materials made by steel slag hydrated matrix
Main uses		Deformed blocks, foot protection blocks, rubble blocks, superstructures (unreinforced concrete), etc.	Crushed stone (armor stone for mild slope revetments), backfill stone, reclamation material
Density		2.3 to 2.6 ton/m^3 (Unit volume mass)	2.1 to 2.9 ton/m^3 (Density in saturated surface-dry condition)
Compressive strength ＊28-day strength (with standard curing)		18 N/mm2 or higher is available *)	
Environmental compatibility	pH	9.0 or less **)	9.0 or less **)
	Biofouling properties	Equivalent to or greater than ordinary Portland concrete	Equivalent to natural stone materials

＊) Design strength of general deformed blocks **) Seawater as the solvent with a solid-to-liquid ratio of 1:10

(3) Low alkalinity
Since the main binder is made from ground granulated blast furnace slag, there is minimal leaching of alkaline components into seawater.

(4) Excellent biofouling properties
Since steelmaking slag, the raw material, contains many essential elements for organisms, such as iron and silica, studies have shown a tendency for it to attract a greater number and larger biomass of attached organisms compared to other materials in marine environments.

(5) Availability of stone materials in any shape and grading
In response to requests from clients and users, hydrated matrix can be produced with specified sieving and grain size distributions. For example, by adjusting the grading distribution, a shear resistance angle (φ_0) of more than 35° can be ensured, and by keeping the 10% passing sieve size (D10) at no more than 2 mm, they can be used as non-liquefiable materials.

Port Repair Work Using Frontier Rock®

Revetment Reinforcement Work Using Blocks Made by Steel Slag Hydrated Matrix

Frontier Rock® before Shipping

Seaweed Attachment to Frontier Rock® and the School of White Croakers Observed

Utilization Technologies for Soft Dredged Soil (Calcia Improved Soil)

Calcia improved soil is a material whose physical and chemical properties have been improved by mixing soft dredged soil, which is generated in large quantities during waterway dredging and other works, with a Calcia modifier. This modifier is made from converter steelmaking slag that has undergone component control and grading adjustment.

When mixed with Calcia modifier, the silica and alumina components in the dredged soil react with the calcium component from the Calcia modifier through hydration and solidification, forming calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (AFm), which improve the strength of the dredged soil.

Additionally, when mixed with dredged soil, the Calcia modifier instantly absorbs the moisture in the dredged soil and acts to suppress material separation. As a result, even when Calcia improved soil is placed in seawater immediately after mixing, the generation of turbidity is reduced.

Furthermore, Calcia improved soil possesses the following characteristics, making it suitable for a wide range of applications.

- Can be shaped to form stable slopes
- Resistant to liquefaction
- Exhibits long-term durability without deterioration in seawater

For example,

(1) When used for reclamation to construct artificial ground in the sea, Calcia improved soil allows for a shorter reclamation period due to its rapid strength development and minimal consolidation settlement.

(2) When used for shallow area and tidal flat foundation development, which serves as both a breeding and nursery ground for organisms and a site for biological water purification, Calcia improved soil allows slopes similar to those of natural shorelines to be created. Furthermore, its strength ensures that habitats for organisms (such as covering sand, artificial reefs, etc.) established on the surface remain stable.

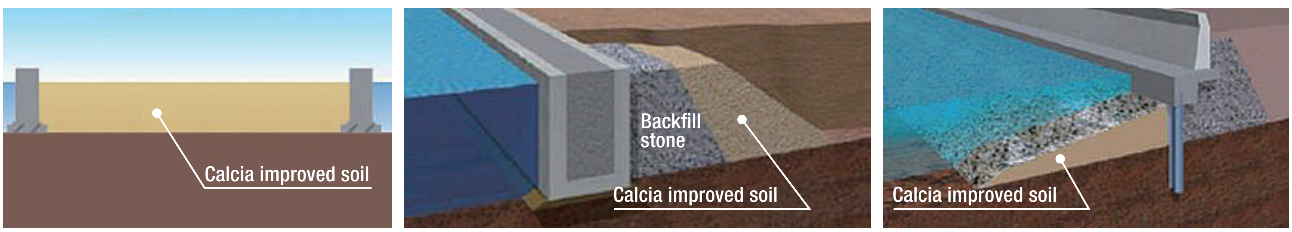
(3) When used for partition dikes to divide a large reclamation area into sections for efficient construction, Calcia improved soil allows dredged soil to be effectively utilized not only as reclamation material but also as a replacement for the natural stone traditionally used in partition dikes.

(4) When used for revetment widening to expand the rear of a revetment in order to increase its stability, Calcia improved soil not only suppresses liquefaction of the ground behind the revetment but also prevents the washout of backfill material without the need for sand protection sheets, thanks to its low permeability.

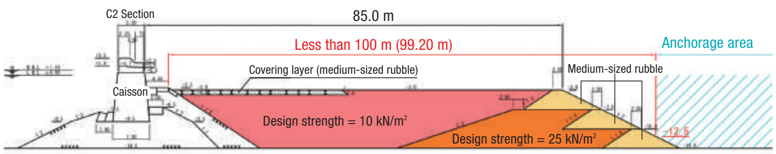
Comparison of Turbidity Suppression Effect

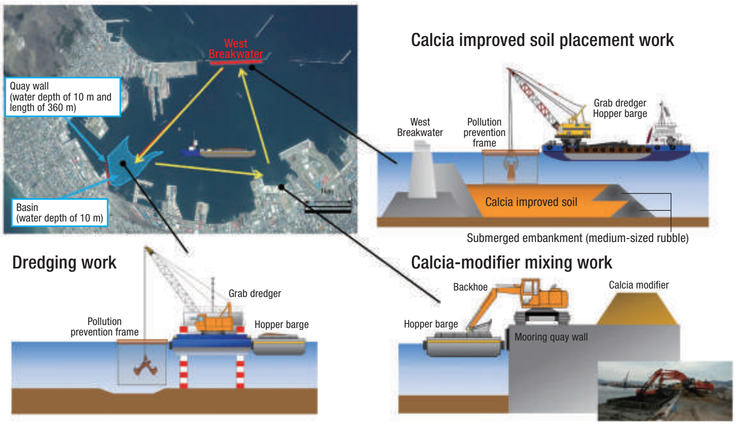
Comparison of turbidity when dredged soil and Calcia improved soil are added to water tanks.

Application Examples of Calcia improved soil
(Left: reclamation material, Center: revetment widening material, Right: shallow-area and tidal flat foundation material)



Overview of 2019 Dredging Work for –10 m Basin at Wakamatsu District in Hakodate Port, Dredging Work at Wakamatsu District in Hakodate Port, Dredging Work for –10 m Basin in Hakodate Port, Dredging Work for Basin in Hakodate Port, and 2020 Dredging Work for Basin at Wakamatsu District and Other Works





Dredged soil generated in the dredging area is transported by a hopper barge to a location where it is mixed with Calcia modifier. After loosening the dredged soil with a backhoe, it is mixed with the Calcia modifier. Calcia improved soil is then placed into the concave areas behind the West Breakwater and within the dredging area. The design strength of Calcia improved soil placed behind the West Breakwater is shown in the diagram on the left.

Construction name: 2019 Dredging Work for –10 m Basin at Wakamatsu District in Hakodate Port, Dredging Work at Wakamatsu District in Hakodate Port, Dredging Work for –10 m Basin in Hakodate Port, Dredging Work for Basin in Hakodate Port, and 2020 Dredging Work for Basin at Wakamatsu District and Other Works; **Construction location:** Area 2 in Hakodate Port for dredging, and Asano and Minato Towns, Hakodate City for Calcia improved soil production, Area 2 in Hakodate Port and the area off the coast of Benten Town, Hakodate City (West Breakwater) for Calcia improved soil placement; **Construction details:** dredging work, soil modification work, soil transportation work, soil disposal work * Dredging work and Calcia improved soil mixed with Calcia modifier used for backfilling the concave areas and for constructing rear embankment; **Construction volume:** Approximately 206,000 m³ of Calcia improved soil; **Client:** Hakodate Development and Construction Department, Hokkaido Regional Development Bureau, the Ministry of Land, Infrastructure, Transport and Tourism; **Contractor:** Toyo-Fuji Salvage Ordinary Construction Joint Venture and Sapporo Branch of Penta-Ocean Construction; **Construction period:** June 2019 to December 2020.

Calcia improved soil Placement Work Procedures Associated with Dredging Work at Wakamatsu District in Hakodate Port

1 Dredging was carried out down to a depth of 10 meters using a grab dredger. **2** The dredged soil was transported to the mixing site, where it was first loosened and then mixed with Calcia modifier. During the first of the five construction phases, a trial mixing operation was conducted over approximately one month. Based on the results, the method was revised from full-dose modifier mixing to a staged addition and mixing process, reducing the mixing time to approximately 60 minutes and improving operational efficiency. **3** A pollution prevention fence was installed around the area of Calcia improved soil placement.

The development of Calcia improved soil began with fundamental research conducted by the Japan Iron and Steel Federation as part of a subsidized project by the Ministry of Economy, Trade and Industry from FY 2004 to 2007. The usefulness and safety of Calcia improved soil, which had been confirmed through laboratory and tank tests, were also verified in actual practice through the construction of a 3,000 m³ mound and subsequent monitoring conducted at the North Basin in Sakai City, Osaka Prefecture. The technical knowledge gained from this project was compiled in the Handbook for Utilizing Converter Steelmaking Slag in Marine Areas and its supplementary volume, Technical Data on the Method for Improving Dredged Soil by Mixing with Converter Steelmaking Slag. Furthermore, the additional knowledge gained through the large-scale 500,000 m³ reclamation project carried out in FY 2012 contributed to the accumulation of further insights, ultimately leading to the publication of the Design and Construction Manual by the Calcia improved soil Study Group.

Since then, with the accumulation of further construction experience, the reliability of the Design and Construction Manual was validated. In FY 2016, the Coastal Development Institute of Technology published the Coastal Technology Library: Technical Manual for the Utilization of Calcia improved soil in Ports, Airports, and Coastal Areas. Following the publication of this manual, additional manuals have been developed, including the Report on Review and Evaluation of Private Technologies Related to Fisheries and Public Works: Calcia-Modification Technology, published in FY 2017 by the Association for Innovative Technology on Fishing Ports and Grounds, and the Cost Estimation Manual for the Calcia-Modified Soil Method, published in FY 2018 by the Calcia improved soil Study Group.

Calcia improved soil has now begun to be adopted in projects by the Ministry of Land, Infrastructure, Transport and Tourism. In the earthquake-resistant quay wall construction carried out by the Shikoku Regional Development Bureau in the Chuo District of Toyo Port, Saijo City, Ehime Prefecture, it was used as backfill material behind the quay wall, offering liquefaction resistance equivalent to that of miscellaneous stone. Additionally, in the dredging work carried out by the Hokkaido Regional Development Bureau at the Wakamatsu District of Hakodate Port in Hakodate City, Hokkaido, Calcia improved soil was used to construct the embankment behind the existing breakwater and to backfill concave areas.

Iron Content Supply Unit Vivary® Unit (Nippon Steel Corporation)

In recent years, a phenomenon known as "rocky-shore denudation" has been occurring along coastal areas throughout Japan, causing significant damage to coastal fisheries. Rocky-shore denudation refers to a condition in which large seaweeds such as kombu and kajime die off and disappear from rocky shores, and instead, unarticulated and articulated calcareous algae cover the rock surfaces, turning the area entirely white.

It is said that rocky-shore denudation occurs due to a combination of factors, including the rise in seawater temperature, excessive activation of herbivores caused by higher temperatures, water quality degradation, and other complex causes. One factor that is also mentioned is the decrease in the supply of humic acid iron to the sea through rivers. Iron fulvic acid was originally generated in humus formed by the accumulation of fallen leaves, but deforestation in upstream river areas has led to a reduction in its supply.

Focusing on the characteristics of steelmaking slag, which contains a high amount of water-soluble iron, Nippon Steel Corporation developed the Vivary® Unit, a system for producing humic acid iron by bagging a mixture of steelmaking slag and fermented waste wood chips. By utilizing this unit, the company is working on the restoration of "sea forests" in coastal areas where iron deficiency has made it difficult for seaweed to grow.

In order to confirm the iron supply effect of the Vivary® Unit, the Marine Greening Association, which promotes industry-academia research on sea forests, has conducted real-world sea area experiments for marine greening across the country, starting with the experiment in Mashike Town, Hokkaido, in 2004, in collaboration with the University of Tokyo and other institutions. In the experiment in Mashike Town, it was confirmed that the Vivary® Unit helped kombu grow abundantly on the sea bottom, which had previously been covered entirely by unarticulated calcareous algae, turning the sea bottom completely white. Within about six months of placing the unit, kombu was seen thriving as far as 30 meters offshore. Additionally, in the subsequent large-scale demonstration project, the Vivary® Unit successfully helped kombu grow along a 300-meter stretch of coastline, extending up to about 50 meters offshore. As a result of this marine greening, it was confirmed that the sea urchin catch nearly doubled, contributing to the promotion of fisheries.

Furthermore, in the report published by the United Nations Environment Programme (UNEP) in October 2009, the carbon incorporated into coastal ecosystems, such as the sea forests created by the Vivary® Unit, was named "blue carbon." Since then, the Vivary® Unit has gained attention as a new carbon dioxide absorption strategy aimed at achieving carbon neutrality. Currently, Nippon Steel Corporation is conducting research on blue carbon, focusing on how the sea forests that the Vivary® Unit has created can contribute to the realization of carbon neutrality.

Growth of Kombu after the Experiment

Large-scale Demonstration Project in Mashike Town, Hokkaido

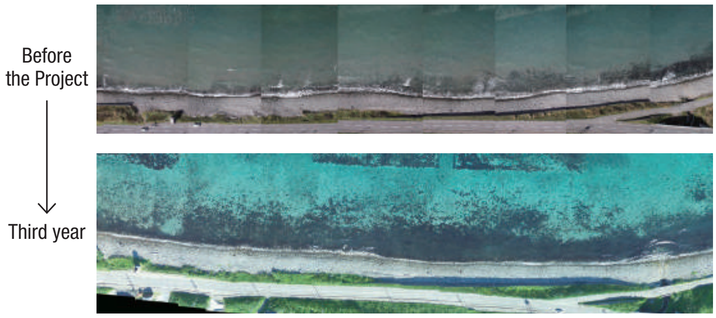
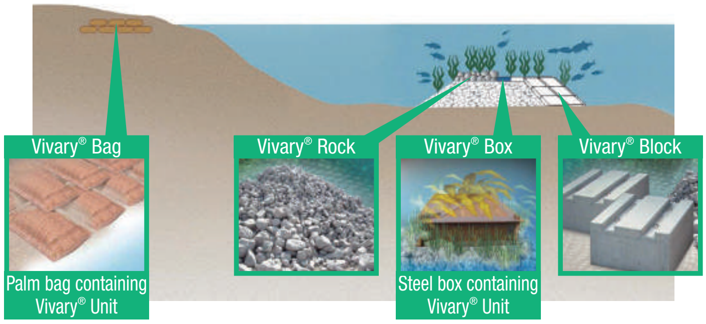


Image of Seaweed Bed Formation Utilizing Iron and Steel Slag Products Including Vivary® Unit



Iron and Steel Slag Carbonated Matrix Marine Block® (JFE Steel Corporation)

Marine Block® is a solidified block produced by exposing steelmaking slag to CO_2-containing gas, causing calcium carbonate to form through the reaction between calcium oxide in the slag and CO_2, which then binds the slag particles together. As calcium carbonate is a component of seashells and coral, Marine Block® is highly compatible with marine organisms and is expected to be used in the creation of artificial coral reefs and seaweed beds. Additionally, by using CO_2-containing gas during production, Marine Block® can contribute to CO_2 emission reduction.

In recent years, coral reefs worldwide have been facing a serious crisis due to factors such as the inflow of sediment from land, the explosive increase in predators like the crown-of-thorns starfish, and the rise in seawater temperature associated with global warming. Using artificial coral reefs with coral larval attachment tools fixed to Marine Block®, JFE Steel Corporation has conducted demonstration research on coral reef restoration. In the demonstration experiment on Miyako Island, it was confirmed that coral larvae had attached to Marine Block®, and coral (Acropora formosa), which had grown to about 20 cm in size after 3.5 years, was present. Additionally, as Marine Block® is porous and steelmaking slag, the raw material for the block, contains nutrient components such as iron and silica, its effectiveness as a substrate for seaweed attachment has been confirmed. Therefore, JFE Steel Corporation is promoting efforts to expand the use of Marine Block® as a substrate material that contributes to the creation and restoration of underwater forests and the enhancement of fishery resources.

Regarding the basic characteristics of Marine Block®, the Waterfront Vitalization and Environmental Research Foundation has published the "Manual for Iron and Steel Slag Carbonated Matrix," which is used as a guide for its application.

Efforts to Restore and Improve Marine Environments Using Marine Block®

Installation of Coral Larval Attachment Tools on Marine Block®

Growth of Kajime on Marine Block®
(Jogashima, Kanagawa Prefecture)

Tropical Fish Gathering Around "Pocillopora Coral"
(Miyako Island, Okinawa Prefecture)

Acropora formosa Growing to a Diameter of 20 cm
(Miyako Island, Okinawa Prefecture)

2 Contribution to a Low Carbon Society

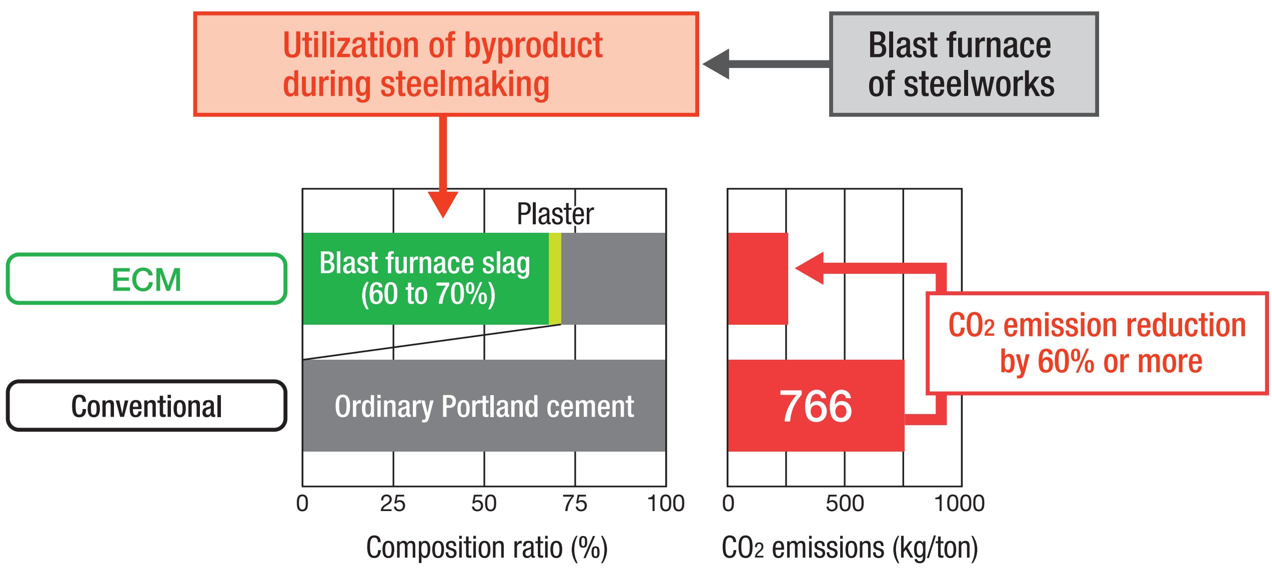
ECM (Energy and CO_2 Minimum) Cement and Concrete Systems

It is estimated that approximately 4% of all greenhouse gas emissions in Japan are derived from the cement industry, with the majority of these emissions occurring during the production of clinker, an intermediate product of Portland cement, through the calcination of limestone. Therefore, in order to reduce the environmental impact of concrete construction as a whole, there have been efforts to reduce energy consumption during cement production by replacing Portland cement with low-environmental-impact materials such as ground granulated blast furnace slag or fly ash, thereby significantly lowering the clinker content in cement. The ECM Cement and Concrete Systems introduced here are examples of low-environmental-impact cement. Efforts to use admixtures as environmental measures in the construction industry are summarized in the brochure titled "Toward the Popularization and Promotion of Low-Carbon Concrete" (*1) published by the Japan Federation of Construction Contractors.

The ECM Cement and Concrete Systems refer to a system for producing and constructing concrete using ECM (Energy and CO_2 Minimum) cement, in which ground granulated blast furnace slag accounts for approximately 60 to 70% of the cement and serves as the primary raw material for hydration. Conventionally, using cement with a high ground granulated blast furnace slag content presented challenges in terms of workability and quality. Therefore, in the development of the ECM Cement and Concrete Systems, ground granulated blast furnace slag was not simply mixed in as a material. Instead, the development focused on a comprehensive solution to the challenges by integrating cement technologies to adjust the chemical composition and grading distribution of ground granulated blast furnace slag, optimizing admixtures, and advancing construction technologies using these innovations. This development was carried out by an industry-academia research team (*2) as a NEDO subsidy project. As a result, the ECM Cement and Concrete Systems succeeded in reducing energy consumption and carbon dioxide (CO_2) emissions in cement production by more than 60% compared to conventional cement production.

Additionally, beyond the reduction in energy consumption and CO_2 emissions, the ECM Cement System has the following characteristics, which have made it applicable to underground building structures, civil engineering structures, ground improvement materials, and other uses.

Estimated CO_2 Emission Reduction by ECM Cement



(1) ECM Cement and Concrete Systems have low hydration and heat generation compared to conventional blast-furnace slag cement, making them highly resistant to thermal cracking.
(2) ECM Cement and Concrete Systems have low drying shrinkage, effectively suppressing shrinkage cracks.
(3) ECM Cement and Concrete Systems have high chemical resistance to chlorides and acids, making them suitable for structures in areas affected by seawater or those using anti-freeze agents.

As a result, the ECM Cement and Concrete Systems have received several awards, including the National Land Technology Development Award from the National Institute for Land and Infrastructure Management, and their widespread adoption is expected to continue growing in the future.

Placement of ECM Concrete

ECM Concrete, which can extend the service life of reinforcing bars by 1.5 times against corrosion due to salt damage, was applied to the concrete structure constructed on the quay wall.

Example of a Pile Using ECM Cement and Concrete Systems

Example of Applying ECM Cement and Concrete Systems to Slab

(＊1) The Environment Committee of the Japan Federation of Construction Contractors, April 2016, http://www.nikkenren.com/publication/detail.html?ci=237

(＊2) Tokyo Institute of Technology, Takenaka Corporation, Kajima Corporation, DC Corporation, Nippon Steel & Sumitomo Metal Blast Furnace Slag Cement (Currently Nippon Steel Blast Furnace Slag Cement, Taiheiyo Cement, Nippon Steel and Sumitomo Metal Cement (Currently Nippon Steel Cement)), and Takemoto Oil & Fat

II List of Standards and Specifications for Iron and Steel Slag Products

Roads

JIS	Iron and steel slag for road construction, JIS A 5015 (2018)
The Public Works Research Center	Guidelines for the Design and Construction of Iron and Steel Slag Road Base Course (2015)

Port Works

The Ports and Harbour Association of Japan	Technical Standards and Commentaries for Port and Harbour Facilities in Japan (Volumes 1 to 3) (2018)
The Coastal Development Institute of Technology	Technical Manual for the Utilization of Granulated Slag in Ports and Airports (2007)
The Coastal Development Institute of Technology	Technical Manual for the Utilization of Steelmaking Slag in Ports, Airports, and Coastal Areas (2015)
The Coastal Development Institute of Technology	Technical Manual for the Utilization of Calcia-Modified Soil in Ports, Airports, and Coastal Areas (2017)
The Japan Iron and Steel Federation	Handbook for Utilizing Converter Steelmaking Slag in Marine Areas (2008)
The Japan Iron and Steel Federation	Handbook for Utilizing Converter Steelmaking Slag in Marine Areas, Supplementary Volume, Technical Data on the Method for Improving Dredged Soil by Mixing with Converter Steelmaking Slag (2008)

Steel Slag Hydrated Matrix

The Coastal Development Institute of Technology	Technical Manual for Steel Slag Hydrated Matrix, Technologies for Effective Utilization of Steelmaking Slag (Revised Version) (2008)

Civil Engineering Works

The Japan Testing Center for Construction Materials	Steelmaking Slag Crushed Stone for Civil Engineering Works, JSTM H 8001 (2016)

Concrete

JIS	Ground granulated blast-furnace slag for concrete, JIS A 6206 (2013)
JIS	Slag aggregate for concrete - Part 1: Blast furnace slag aggregate, JIS A 5011-1 (2018)
JIS	Slag aggregate for concrete - Part 4: Electric arc furnace oxidizing slag aggregate, JIS A 5011-4 (2018)
JIS	Ready-mixed concrete, JIS A 5308 (2019)
The Architectural Institute of Japan	Recommendations for Practice of Blast Furnace Slag Crushed Stone Concrete (1978)
The Architectural Institute of Japan	Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate (Draft) (2005)
The Architectural Institute of Japan	Recommendations for Practice of Concrete with Blast Furnace Slag Fine Aggregate (2013)
The Architectural Institute of Japan	Recommendation for Design and Practice of Reinforced Concrete Building with Portland Blast-Furnace Slag Cement or Ground Granulated Blast-Furnace Slag (Draft) (2017)
The Japan Society of Civil Engineers	Guidelines for Construction of Concrete Using Blast Furnace Slag Aggregate (1993)
The Japan Society of Civil Engineers	Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate (Draft) (2003)
The Japan Society of Civil Engineers	Recommendations for Design and Construction of Concrete Using Ground Granulated Blast-Furnace Slag (2018)
The Japan Society of Civil Engineers	Recommendations for Design and Construction of Concrete Structures Containing High-Volume Mineral Admixtures (Draft) (2018)
The Japan Society of Civil Engineers	Guideline on Design, Manufacture and Construction of Methods of Precast Concrete with Blast-Furnace Slag Sand (Draft) (2019)

Cement

JIS	Portland cement, JIS R 5210 (2009)
JIS	Portland blast-furnace slag cement, JIS R 5211 (2009)

Abrasives

JIS	Non-metallic blast-cleaning abrasives, JIS Z 0312 (2016)

III History of Iron and Steel Slag Utilization

1900

1901	Commencement of integrated steelmaking at the government-operated Yawata Steel Works (current Yawata Area, Kyushu Works, Nippon Steel Corporation)
1907	Production of slag bricks with hydrated lime and granulated slag
1910	Commencement of cement production using blast furnace slag
1925	Notification on Blast-Furnace Slag Cement issued by the Ministry of Commerce and Industry
1955	Standards for calcium silicate fertilizer
1966	Establishment of the Slag Products Research Association
1976	Establishment of the Slag Resource Recycling Committee in the Japan Iron and Steel Federation
1977	Enactment of JIS A 5011 Blast furnace slag coarse aggregate for concrete
1978	Publication of the Recommendations for Practice of Blast Furnace Slag Crushed Stone Concrete (Draft) (by the Architectural Institute of Japan and the Japan Society of Civil Engineers)
1979	Enactment of JIS A 5015 Iron and steel slag for road construction
1981	Enactment of JIS A 5012 Blast furnace slag fine aggregate for concrete
1983	Publication of the Recommendations for Design and Construction of Concrete Using Blast-Furnace Slag Fine Aggregate (Draft) (by the Architectural Institute of Japan and the Japan Society of Civil Engineers)
1987	Publication of the Guidebook for the Use of Steelmaking Slag in Port Construction
1989	Adoption of blast-furnace slag cement as a measure to mitigate alkali-aggregate reaction (Ministry of Construction Notification)
1992	Incorporation of steelmaking slag into JIS A 5011 Blast furnace slag coarse aggregate for concrete and Revised JIS A 5015 Iron and steel slag for road construction
1995	Enactment of JIS A 6206 Ground granulated blast-furnace slag for concrete
1997	Publication of the Recommendations for Practice of Concrete with Blast Furnace Slag Fine Aggregate (Draft) (by the Architectural Institute of Japan)
1997	Enactment of JIS A 5011-1 Slag aggregate for concrete - Part 1: Blast furnace slag aggregate

2000

2000	Publication of the Guidebook for the Use of Steelmaking Slag in Port Construction (by the Coastal Development Institute of Technology and the Nippon Slag Association)
2001	Selection of blast-furnace slag cement for the first time as the first designated procurement item under the Act on Promoting Green Procurement
2003	Publication of the Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate (by the Japan Society of Civil Engineers)
	Enactment of JIS A 5011-4 Slag aggregate for concrete: Electric arc furnace oxidizing slag aggregate
2005	Publication of the Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate (Draft) (by the Architectural Institute of Japan)
2007	Publication of the Technical Manual for the Utilization of Granulated Slag in Ports and Airports (by the Coastal Development Institute of Technology)
2008	Enactment of JSTM H 8001 Steelmaking Slag Crushed Stone for Civil Engineering Works (by the Japan Testing Center for Construction Materials)
	Publication of the Handbook for Utilizing Converter Steelmaking Slag in Marine Areas (by the Japan Iron and Steel Federation)
	Publication of the Technical Manual for Steel Slag Hydrated Matrix (Revised Version) (by the Coastal Development Institute of Technology)
2013	Revision of JIS A 6206 Ground granulated blast-furnace slag for concrete
	Publication of the Recommendations for Practice of Concrete with Blast Furnace Slag Fine Aggregate (by the Architectural Institute of Japan)
2015	Publication of the Guidelines for the Design and Construction of Iron and Steel Slag Road Base Course (by the Public Works Research Center)
	Publication of the Technical Manual for the Use of Steelmaking Slag in Ports, Airports, and Coastal Areas (by the Coastal Development Institute of Technology)
2016	Revision of JSTM H 8001 Steelmaking Slag Crushed Stone for Civil Engineering Works (by the Japan Testing Center for Construction Materials)
2017	Publication of the Recommendation for Design and Practice of Reinforced Concrete Building with Portland Blast-Furnace Slag Cement or Ground Granulated Blast-Furnace Slag (Draft) (by the Architectural Institute of Japan)
	Publication of the Technical Manual for the Utilization of Calcia-Modified Soil in Ports, Airports, and Coastal Areas (by the Coastal Development Institute of Technology)
2018	Revision of JIS A 5011-1 Slag aggregate for concrete - Part 1: Blast furnace slag aggregate
	Revision of JIS A 5011-4 Slag aggregate for concrete - Part 4: Electric arc furnace oxidizing slag aggregate
	Revision of JIS A 5015 Iron and steel slag for road construction
	Publication of the Recommendations for Design and Construction of Concrete Using Ground Granulated Blast-Furnace Slag (by the Japan Society of Civil Engineers)
	Publication of the Recommendations for Design and Construction of Concrete Structures Containing High-Volume Mineral Admixtures (Draft) (by the Japan Society of Civil Engineers)
2019	Publication of the Guideline on Design, Manufacture and Construction of Methods of Precast Concrete with Blast-Furnace Slag Sand (Draft) (by the Japan Society of Civil Engineers)

About the Nippon Slag Association

Purpose and Activities of the Association

The purpose of this Association is to foster an understanding of iron and steel slag among industries, government agencies, and academic associations, and to promote its effective utilization.
Through our promotional activities, we are advancing the following initiatives to contribute to society, including the establishment of a recycling-oriented society, measures to combat global warming, and the protection of natural resources.

1. Investigation and research on the quality of iron and steelmaking slag products and the technologies related to it

(1) Research and investigation for maintaining and improving quality
(2) Research and investigation on utilization technologies
(3) Promotion of application development and standardization of various applications

2. Information collection and promotional activities related to production and demand for iron and steel slag products

(1) Preparation of various statistics related to iron and steel slag products
(2) Publicity and promotional activities related to iron and steel slag products

History of the Association

February 1966	Establishment of the Slag Products Research Association in Osaka City
July 1968	Renamed to the Japan Slag Association
April 1975	Relocation of the headquarters to Tokyo Metropolis and establishment of the Osaka Office
May 1976	Renamed to the Japan Slag Association
October 1978	Dissolution of the Japan Slag Association and establishment of the Nippon Slag Association through the integration of steel manufacturers.
April 1981	Affiliation of Non-Integrated Steel Producers' Association and member companies of the Special Steel Subcommittee
April 1984	Took over the operations of the Slag Recycling Committee of the Japan Iron and Steel Federation

Member Companies and Organizations of the Nippon Slag Association

(Currently 19 member companies and 2 member organizations)

Kyozaisaiseki	DC Corporation	Nippon Steel Cement
Kobe Steel	Tetsugen Corporation	Nippon Magnetic Dressing
Sanyo Special Steel	Toho Kinzoku	Nippon Steel Corporation
JFE Steel Corporation	Nakayama Steel Works	Hamada Heavy Industries
JFE Mineral & Alloy	Nisshin Kogyo	HOSHINO SANSHO
Seishin	Nippon Steel Blast Furnace Slag Cement	The Japan Iron and Steel Federation
Daido Steel	Nippon Steel Slag Products	Non-Integrated Steel Producers' Association

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