

Performance comparable or superior to that of natural crushed stones.

Mining is unnecessary, contributing to environmental conservation Artificial stone material (Frontier Stone™, Frontier Rock™)

Features

- The quality is comparable with that of semi-hard stone.
- The material is made-to-order in a size suitable for the use intended by the customer. The artificial stone materials Frontier Stone and Frontier Rock are available in particle sizes of 300 mm or less, and 100 to 1000 mm, respectively.
- It was revealed that the organism (algae) growth on Frontier Stone and Frontier Rock are comparable with that on natural stone or concrete blocks.

Features of Frontier Stone and Frontier Rock

Table 1. Summary of the features of Frontier Stone and Frontier Rock

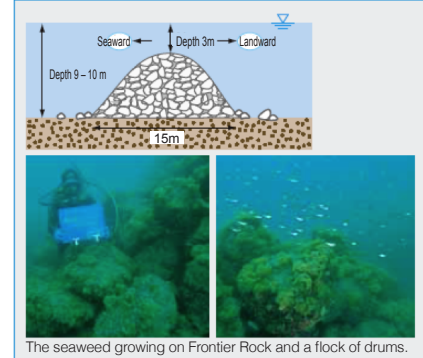
Type of artificial stone materials	Frontier Stone	Frontier Rock
Application	Reclamation materials	Rubble (gentle slope revetment/armor stone)/backfill stone
Country rock quality	Compressive strength: 9.8 N/mm ² or higher Water absorption: 5 - 20%	Bone dry density: 1.8 - 2.7 g/cm ³
Grade/weight	Range of grade/weight	0~300mm / 5~2000kg (100~1000mm ^{※1})
	Uc	5~40 / 1.3~3 ^{※2}
Mechanical properties	D10	1 mm or larger / -
	Angle of shear resistance	35° or higher / Uc ≥ 5: φ 35° or greater
	Secondary coefficient of compressibility	Equivalent to natural semi-hard stone ^{※3} / -
Environmental compatibility	Staking rate	- / -
	pH	9.0 or lower (dissolved in seawater, solid-liquid ratio 1:10)
Expansion	Organism growth	- / Equal to or greater than natural stone materials
	Elution of hazardous materials	Equal to or less than the levels specified as the dredge soil criteria in the "Law Relating to the Prevention of Marine Pollution and Maritime Disaster, or the Environmental Quality Standards for Soil Contamination."
	Expansion	Not observed ^{※4} / No hazardous cracks. ^{※5}

^{※1}: Contact the manufacturer for the availability of product with a particle size of 500 mm or larger. ^{※2}: The value must be 5 or greater to guarantee the angle of shear resistance of 35°. ^{※3}: IKENO Katsuya, SHINSHA Hiroshi / KAWAMURA Kensuke: An experiment on the applicability of rock debris to reclamation materials - long-term compressibility, the 40th Japan National Symposium on Geotechnical Engineering, the Japanese Geotechnical Society, 2005. ^{※4}: Approximately 0.2% or less by the expansion stability test (80 °C immersion method) (JIS A 5015). ^{※5}: Steel slag solid hydration product manual, Appendix 2.

Table 2. Mix proportion examples

No.	Unit quantity (kg/m ³)					
	Water	Ground granulated blast furnace slag	Fly ash	Steel slag	Alkaline activator	Chemical admixture
No.1	230	460	-	1692	-	-
No.2	230	460	-	1326	-	-
No.3	186	297	125	2038	53	2.85
No.4	166	297	85	2021	53	1.76
No.5	174	316	63	2111	57	2.61
No.6	300	450	-	1539	-	-
No.7	300	525	-	1463	-	-

Construction of an artificial seaweed reef at Miura bay, Mie prefecture.



Applicable field
Reclamation materials for liquefaction prevention (including dividers), submerged breakwaters, backfill stone, armor stone, etc., substrates for natural stone materials equivalent to semi-hard stones.

Water
Energy saving/Energy recovery
Energy storage/Energy creation
New energy
Waste disposal/Recycling/Resource saving
Air
Soil
Other

Overview

(Technical principles, actions, etc.)

This artificial stone made from a steel slag solid hydration product (referred to as 'artificial stone' hereafter) uses steel slag as an aggregate at 50% or more, and is manufactured by mixing ground granulated blast furnace slag and water, and solidifying (curing) the mixture by hydration reaction. It is one of the designated procurement items specified as an environmentally-friendly material by the Law Concerning the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities (Law on Promoting Green Purchasing), and protects the natural environment and reduces CO₂ by reducing the amount of cement consumption.

The steel slag material has a density higher than that of natural aggregates (density in saturated surface-dry condition: steel slag = 2.8 - 3.6 g/cm³, natural aggregate 2.6 - 2.7 g/cm³), and a higher bulk density which is 2.3 - 2.6 t/m³ at the standard mix proportion (normal-weight concrete = approximately 2.3 t/m³).

In addition, an angle of shear resistance 35° or greater is obtained at a confining pressure of 100 - 400 kPa.

This artificial stone features rich elements suitable for the growth of seaweed and other organisms, and the wave stability due to the high specific gravity makes it a suitable material for unreinforced port construction work as tetrapods, foot protection blocks, armor blocks or as an alternative to rubble mound materials.

Introductory Track Record

Major cases of application

Construction project	Applications	Size	Quantity used (m ³)
Haneda Airport runway D exterior construction	Divider	0~300mm	250,000
Haneda Airport runway D exterior construction	Reclamation	0~100mm	350,000
Tideland construction around the Tokyo International Airport	Tideland construction materials	1,000kg/unit	10,950
Port of Shimonoseki (new port), one construction project on the outside of the cofferdam	Armor stone	100~300kg/single unit	20,000

Effects

[Comments]

- This artificial stone has mechanical properties comparable with that of semi-hard stone, and can be made-to-order in a size suitable for the use intended by the customer (up to approximately 1000 mm).
- The steel slag mainly used as the aggregate and binder protects the natural environment and reduces CO₂ emissions by 60% (※). The material is one of the designated procurement items specified by the Law Concerning the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities.
- The high bulk density of 2.4 - 2.6 t/m³ at the standard mix proportion (normal-weight concrete = approximately 2.3 t/m³) provides good wave stability.
- The steel slag and other materials are rich in iron, and contain silicon and other essential elements required by organisms, and increase the number of organism species and the amount of organism growth under the marine environment.

※Excerpted from the Coastal Development Institute of Technology: Report on the review and evaluation of private sector harbor and coastal engineering, No. 07001, 2007.

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※Note: This publication introduces examples of technologies and products believed useful towards solving environmental and energy issues. In no way does it constitute guarantees concerning their transfer or sale.