Appendix
Introduction of CO_2 reduction and utilization technologies in the Cement and Concrete Sectors

No.	CO_2 countermeasure technologies	Company or organization that uses the technology
[1]	CO_2-SUICOM	Kajima Corporation
[2]	CO_2-TriCOM	The Chugoku Electric Power Co., Inc.
[3]	DAC Coat	Shimizu Corporation
[4]	Concrete using carbonated recycled aggregate	Tokyo Electric Power Company Holdings, Inc.
[5]*	CarbonCure	Mitsubishi Corporation
[6]	T-Carbon Mixing	Taisei Corporation
[7]*	O.C.O Technology Limited	Kobelco Eco-Solutions Co., Ltd. and Mitsubishi Corporation
[8]*	Blue Planet	Mitsubishi Corporation
[9]	CCC (C^4S Project)	The University of Tokyo and Hokkaido University
[10][15][24][26]	T-*e*Concrete series	Taisei Corporation
[11]	Clean-Crete N	Obayashi Corporation
[12]	SUSMICS-C	Shimizu Corporation
[13]	LigninCrete	Obayashi Corporation
[14]	ECM Concrete	Kajima Corporation
[16]	Super Green Concrete	Maeda Corporation
[17]	LHC (Low Carbon High-performance Concrete)	Hazama Ando Corporation
[18]	BBFA High Strength Concrete	Hazama Ando Corporation
[19]	Ashcrete	Hazama Ando Corporation
[20]	Geopolymer (Geopoly)	Nishimatsu Construction Co., Ltd.
[21]	AAM Concrete	Nishimatsu Construction Co., Ltd.
[22]	Cast-in-place Geopolymer (PolymerCrete)	Obayashi Corporation
[23]	Sustain-Crete	Sumitomo Mitsui Construction Co., Ltd.
[25]	Clean-Crete	Obayashi Corporation
[27]	Slagrete	Toda Corporation

* At the request of the company that uses the technology, the overview document has been omitted.

CO_2-SUICOM by Kajima Corporation [1]

(1) Outline of the technology

CO_2-SUICOM (CO_2 Storage and Utilization Infrastructure by COncrete Materials), is an environmentally friendly concrete jointly developed by the Chugoku Electric Power Co. Inc., Kajima Corporation, Denka Company Limited, and LANDES Co. Ltd. The utilization of industrial by-products and the storage of large amounts of CO_2 through accelerated carbonation (carbonation curing) results in CO_2-SUICOM concrete that is carbon negative.

[1] Reduction in cement usage through the replacement with industrial byproducts

Since most of the CO_2 emissions attributable to construction using concrete are derived from cement production, a reduction in cement usage represents an effective means of curbing CO_2 emissions. In CO_2-SUICOM, the cement usage is reduced to about one-third in comparison to that used in conventional concrete by replacing it with a combination of industrial by-products such as ground granulated blast furnace slag, and γ-C_2S. γ-C_2S is a special admixture that has a composition similar to that of cement, however, it hardens on reaction with CO_2, and not water. The CO_2 emission during the production of γ-C_2S is about one-fifth of that compared to cement because it is synthesized using waste calcium hydroxide and is calcined at a lower temperature compared to cement. Hence γ-C_2S is an effective low CO_2 emitting alternative to cement.

[2] CO_2 storage through carbonation curing

CO_2-SUICOM concrete is able to efficiently absorb and hence store waste CO_2 during carbonation curing because it contains the special admixture γ-C_2S. For instance a potential place of application could be the CO_2 gas present in the exhaust gas generated by thermal power plants that can be stored in concrete. When using the exhaust gas from thermal power plants (CO_2 concentration of 10 to 20%) as the source, de-moulded pre-cast CO_2-SUICOM concrete products are first placed inside a specially designed curing tank that is located within the thermal power plant. The carbonation curing of the concrete is achieved by controlling the temperature and humidity inside this curing tank and keeping it at a certain level to ensure efficient CO_2 absorption and storage.

Figure 1.1 Curing tank installed at a thermal power plant

Figure 1.2 Loading CO_2-SUICOM concrete products into the carbonation curing tank

(2) Amount of CO_2 reduction and applications

[1] Amount of reduction in CO_2 emission and absorption using CO_2-SUICOM

Figure 1.3 presents a comparative analysis of the carbon footprint of conventional pedestrian curb blocks with those manufactured using CO_2-SUICOM. The total reduction in CO_2 emissions achieved by CO_2-SUICOM is 306 kg/m^3, of which 197 kg/m^3 is attributable to a reduction in cement usage to approximately one-third of that used in conventional curb blocks. This reduction in cement usage was achieved by replacing it with industrial by-products such as ground granulated blast furnace slag or fly ash, and the previously described special admixture γ-C_2S. Moreover, an additional reduction of 109 kg/m^3 was achieved through the storage of CO_2 in the curb blocks during the carbonation curing process. Therefore, CO_2-SUICOM is a special type of concrete that is capable of achieving a significant reduction in CO_2 emissions when compared to products manufactured using conventional concrete and can attain carbon negativity with a CO_2 balance of -18 kg/m^3.

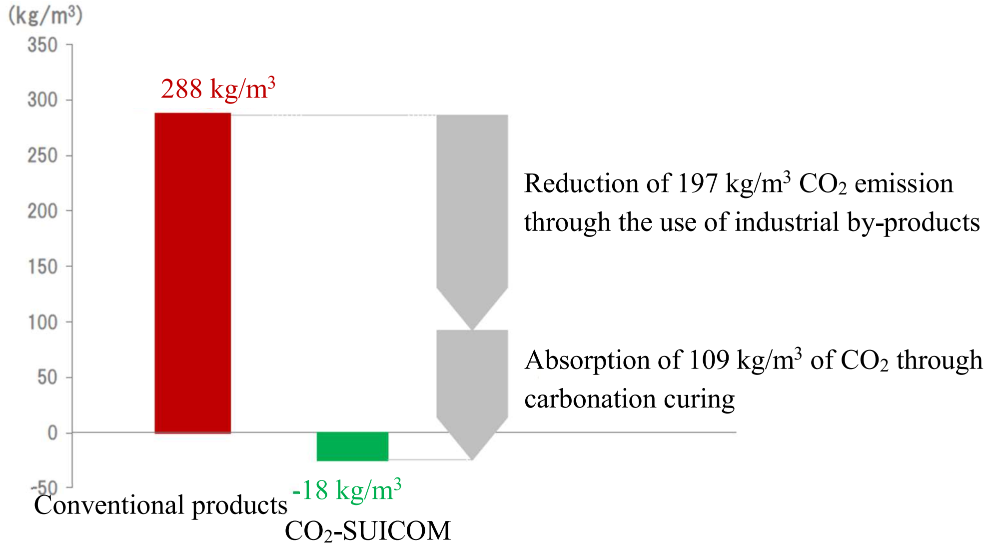


Figure 1.3 Comparison of CO_2 emissions from pedestrian curb blocks

[2] Application of CO_2-SUICOM

Since 2011, CO_2-SUICOM has been employed in the manufacture of numerous precast concrete products for application in a variety of construction projects.

- Pedestrian curb blocks (5 projects)
- Interlocking blocks (3 projects)
- Stay-in-place formwork (4 projects)
- Other (architectural precast panels of a building, foundation blocks, revetment blocks, and finishing blocks)

Figure 1.4 Pedestrian curb blocks made of CO_2-SUICOM

(3) Future prospects

Currently, the application of CO_2-SUICOM is limited to precast concrete products, mainly due to the manufacturing process wherein CO_2 is absorbed by CO_2-SUICOM concrete in a carbonation chamber. Technological advancement has been underway to facilitate the application of CO_2-SUICOM to cast-in-place concrete structures, with the objective of commercializing it by the mid-2020s.

CO_2-TriCOM by the Chugoku Electric Power Co., Inc. [2]

(1) Outline of the technology

CO_2-TriCOM is a recycling technology that converts waste concrete powder generated during the recycling of concrete electric poles, and coal ash produced from thermal power plants into civil engineering materials. This process is categorized as carbon mineralization in the carbon recycling sector. In CO_2-TriCOM, CO_2 is fixed through the production of calcium carbonate ($CaCO_3$) by sintering a mixture of coal ash, waste concrete powder, and CO_2 generated from thermal power plants. In this process, calcium oxide (CaO) contained in the waste concrete powder is reacted with CO_2 to produce carbonate ($CaCO_3$), in which fixes the CO_2. CO_2-TriCOM is named after the concept of Triple CO Capture Material, referring to a molecular structure consisting of three CO molecules. A visual representation of CO_2-TriCOM is shown in Figure 2.1.

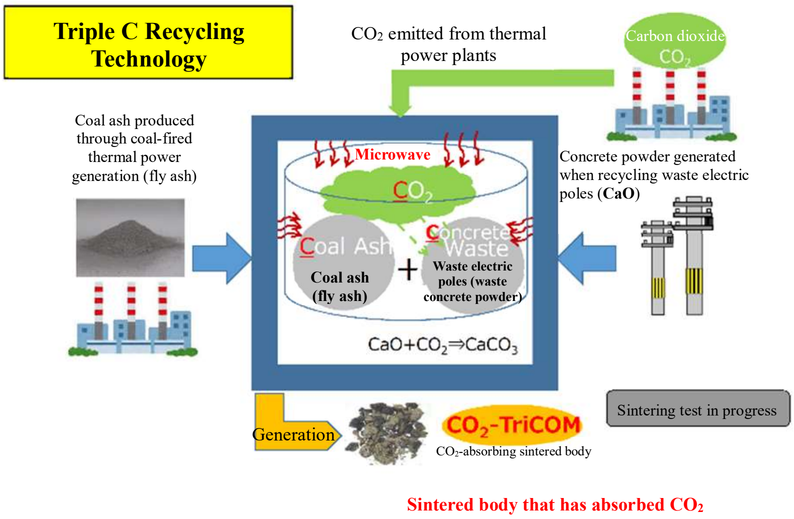


Figure 2.1 Visual representation of CO_2-TriCOM

Coal ash generated from coal-fired thermal power plants is largely separated into fly ash and clinker ash. The application of fly ash is primarily limited to fly ash concrete and other materials. In contrast, clinker ash has a wide range of applications, from greening base materials to lightweight embankment materials and drainage materials. The sintered body produced through this technology has physical properties similar to clinker ash. Therefore, CO_2-TriCOM is expected to be used in a wide range of applications, from lightweight embankment materials to greening base materials and more.

This technology was jointly developed by the Chugoku Electric Power Co., Inc., Hiroshima University, and Chugoku Koatsu Concrete Industries Co., Ltd. through the publicly offered program by the New Energy and Industrial Technology Development Organization (NEDO) for the "Development of Technologies for Carbon Recycling and Next Generation Thermal Power Generation / CO_2 Emission Reduction and Practical Application of Effective CO_2 Use / Utilization of CO_2 in Concrete, Cement, Carbonate, Carbon, Carbon Oxide, etc." The application was approved in July 2020. Chubu University also participated in the development as a subcontractor for Chugoku Koatsu Concrete Industry Co., Ltd.

(2) Estimated or actual CO_2 reduction rates

This technology aims to achieve a CO_2 absorption rate of 60 kg per ton of sintered body. However, heating the sintered body with microwaves consumes electricity, which results in CO_2 emissions. Thus, the research and development goal has been set to achieve a CO_2 balance of 167 kg per ton by halving electric power consumption and achieving CO_2 absorption of 60 kg per ton of sintered body. CO_2-TriCOM is expected to improve the CO_2 balance compared to other competitive materials.

(3) Future prospects

Research efforts will continue in an effort to achieve commercialization by 2030, with a target production amount of 50,000 tons per year.

References

1) Keita Kagawa: "The First Technology Using Microwaves to Absorb CO_2 in Japan, CO_2-TriCOM," *Chemical Engineering of Japan*, Vol. 85, pp. 342–344.
2) Keita Kagawa, Shota Miyamoto, et al.: "Research and Development of CO_2 Absorption Sintered Bodies Using Microwaves (CO_2-TriCOM)," Proceedings of the Thermal and Nuclear Power Generation Convention 2022, Hiroshima.
3) Keita Kagawa, Shota Miyamoto, et al.: "Research and Development of CO_2 Absorption Sintered Bodies Using Microwaves, CO_2-TriCOM," *JEMEA Bulletin*, Vol. 8, pp 11–13.

DAC Coat by Shimizu Corporation [3]

(1) Outline of the technology

DAC (Direct Air Capture) Coat is a technology that absorbs and fixes CO_2 from the atmosphere using concrete structures treated with an impregnation agent applied to their surfaces (see Figure 3.1). Since concrete is naturally alkaline, it absorbs CO_2 from the atmosphere. DAC Coat can increase the CO_2 absorption rate of concrete by 1.5 times.

Traditionally, the phenomenon of concrete absorbing CO_2 has been regarded as a deterioration process, where the pH of the concrete decreases, leading to the corrosion of the reinforcing steel. However, the DAC coat can both promote CO_2 fixation in concrete and protect the reinforcing steel from corrosion. This is made possible by the properties of its main component, an amine compound. Furthermore, this anti-corrosion effect contributes to extending the lifespan of concrete structures.

Figure 3.2 shows a comparison of the simulated CO_2 fixation amounts in concrete with and without the application of DAC Coat over five years. The figure also shows changes in the composition of concrete at different depths from the surface. It clearly illustrates that applying DAC Coat enables concrete to produce a larger quantity of $CaCO_3$ at greater depths compared to concrete without DAC Coat. The $CaCO_3$ shown in the figure was produced as a result of the reaction between CO_2 and calcium hydroxide in the concrete and the quantity of $CaCO_3$ corresponds to the CO_2 fixation amount.

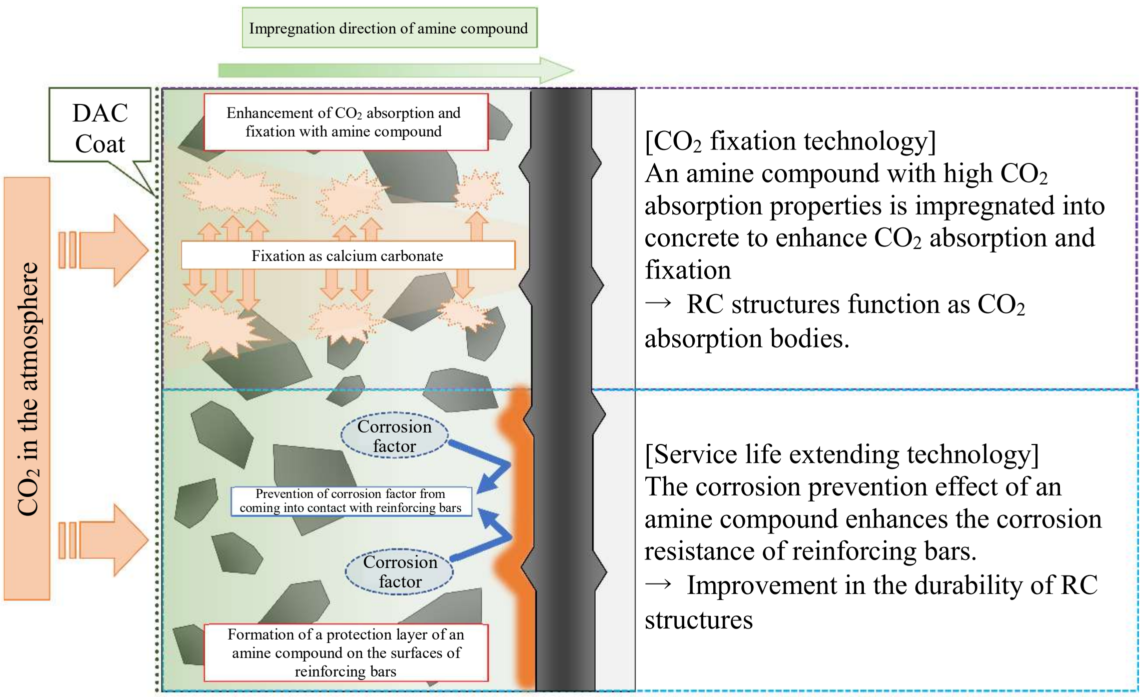


Figure 3.1 Schematic diagram of DAC Coat

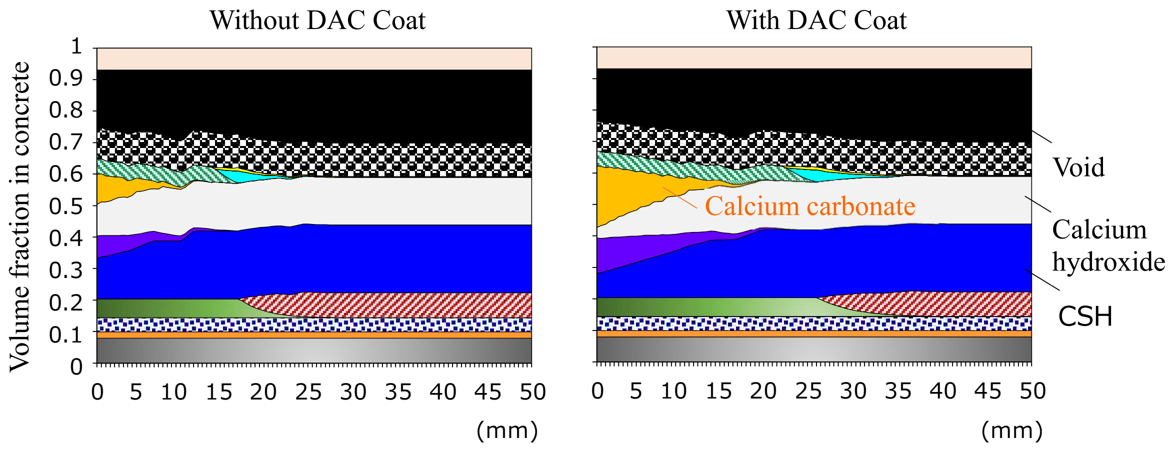


Figure 3.2 Comparison of CO_2 fixation amounts in concrete with and without the application of DAC Coat over five years (simulation)

(2) Wide applicability to both existing and new concrete structures

DAC Coat is characterized by its wide applicability to both existing and new concrete structures. The volume of concrete structures in Japan is estimated to be over 10 billion cubic meters. It is said that 1 cubic meter of concrete fixes about 18 kg of CO_2. The application of DAC Coat can increase the fixation amount to 27 to 36 kg. This means that DAC Coat has the potential to absorb upwards of 300 million tons of CO_2 if applied to all the exposed surfaces of existing concrete structures. Additionally, DAC Coat further enhances CO_2 absorption when applied to recycled aggregate or concrete debris generated from dismantled structures.

(3) Future prospects

Capable of both enhancing CO_2 fixation and extending the service life of concrete structures, DAC Coat gives concrete new value as a CO_2-absorbing storage (carbon credits).

In the future, industry-academia collaboration will be accelerated with the goal of commercialization around 2026. To achieve this, ongoing efforts will focus on laboratory performance evaluation, full scale performance verification, standardization of construction methods, incorporation of DAC Coat into the carbon credit system, and other related actions.

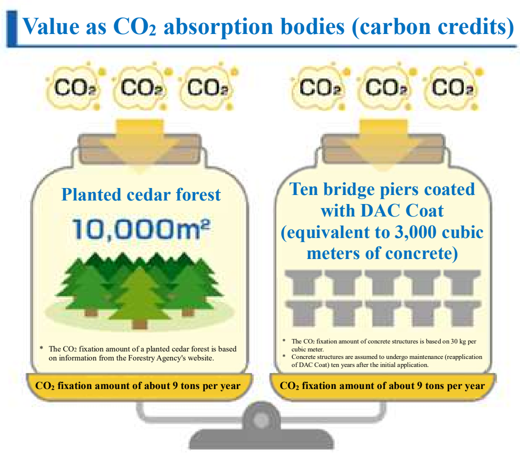


Figure 3.3 Creating new value for concrete structures

Concrete using carbonated recycled aggregate by Tokyo Electric Power Company Holdings, Inc. [4]

(1) Outline of the technology

Carbonated recycled aggregate is recycled aggregate with improved qualities, such as density and moisture absorption rate, achieved by densifying the adhered mortar through forced carbonation. This process is applied to recycled aggregate classified as quality categories M or L. This technology aims to enhance the utilization of recycled aggregate, which has been limited by cost and other factors, by achieving CO_2 fixation and quality improvements. This will contribute to a higher level of resource circulation in the concrete sector. Currently, Tokyo Electric Power Company Holdings, Inc. is in the process of verifying and implementing carbonated aggregate and concrete made with it.

Figure 4.1 Recycled aggregate

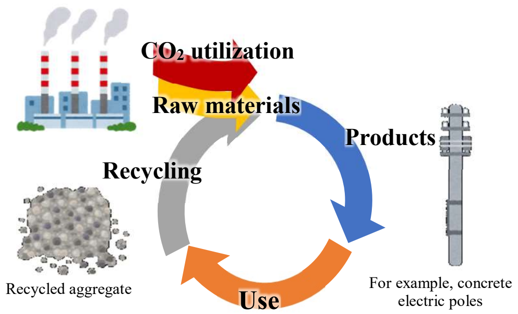


Figure 4.2 Resource utilization cycle for carbonated recycled aggregate

[1] Simple production process

The carbonation curing of carbonated recycled aggregate primarily uses boiler exhaust gases (with a CO_2 concentration of 5 to 15%), including those from thermal power plants, and does not require highly concentrated gases. Thus, carbonated recycled aggregate can be produced through a simple process that does not require CO_2 separation, capture, or heating. Basically, the energy consumed during the production process (CO_2 emissions) does not exceed that of producing natural aggregate.

The production process for concrete made with carbonated recycled aggregate is essentially the same as that for standard concrete.

[2] Influences on concrete

Compared to using general (non-carbonated) recycled aggregate, concrete made with carbonated recycled aggregate can improve many physical properties, including preventing the reduction in compressive strength, similar to that of standard concrete. Therefore, using carbonated recycled aggregate within the normal usage range does not cause a significant increase in unit cement amount. However, like general recycled aggregate, carbonated recycled aggregate also requires careful consideration when used in concrete exposed to severe conditions such as dry shrinkage or freeze-thaw cycles.

This technology exclusively carbonates aggregate and therefore does not cause corrosion of steel materials due to the neutralization of the entire concrete member. Additionally, this technology can be combined with other carbon-neutral technologies, such as cementless concrete and CO_2 absorption technologies, which have already been used in Japan.

(2) Estimated or actual CO_2 reduction rates

Previous research[1)] reported that the mass increase due to the carbonation of recycled aggregate varies depending on aggregate classification and, as shown in Table 4.1, ranges from 0.7% to 2.8% with respect to sample mass. It is too early to tell if the change in mass is all due to CO_2 fixation. However, considering that the change in the amount of calcium carbonate closely corresponds to the change in mass, the extent of CO_2 fixation due to forced carbonation of recycled aggregate is considered to correspond to the change in mass (equivalent to 7 to 28 kg of CO_2 per ton of sample). Additionally, since carbonated recycled aggregate can be produced by directly using exhaust gas and undergoing simple processes such as mild crushing and classification, the energy consumption during production does not exceed that of natural aggregate. Therefore, the amount of CO_2 fixed through carbonation is believed to directly contribute to reducing CO_2 emissions.
The annual generation of waste concrete in Japan is 37 million tons. If all of this were used as a latent market for carbonated recycled aggregate, it would have the potential to fix about 1 million tons of CO_2 per year.

Table 4.1 Change in mass (%) of recycled aggregate due to forced carbonation

	Recycled coarse aggregate M	Recycled coarse aggregate L	Recycled fine aggregate L	Material obtained by crushing electric poles
Actual maximum value	0.4	1.5	2.8	0.7

(3) Future prospects

The momentum in the concrete sector towards the recycled use of resources is expected to increase further in the pursuit of a sustainable society. Therefore, the use of recycled aggregate is expected to become more widespread. In this context, there are high expectations for the widespread adoption of carbonated recycled aggregate, which offers improved quality and the added benefit of CO_2 fixation.
The widespread use of carbonated recycled aggregate in general concrete is not anticipated due to constraints such as standards. Therefore, during the initial introduction period, it is essential to accumulate successful applications of carbonated recycled aggregate for specific purposes and products. To facilitate its widespread adoption, the expansion of production bases is planned not only at thermal power plants but also at urban factories, leveraging its simple production process and involving many companies.

Reference

1) Yoshitaka Matsuura, Yasushi Kobayashi, Hiroyuki Aoyama, and Kiminori Ozaki: "Basic Study on the Quality of Carbonated Recycled Aggregate and Material Obtained by Crushing Electric Poles," *Proceedings of the Japan Concrete Institute*, Vol. 45, No.1, pp. 1246-1251 (2023).

T-Carbon Mixing by Taisei Corporation [6]

(1) Outline of the technology

This technology fixes CO_2 in concrete by directly spraying it over the concrete during the kneading process.

• Kneading concrete in two stages

Primary kneading is carried out on 10 to 30% of the concrete materials, excluding coarse aggregate. During this process, CO_2 is directly sprayed onto the concrete materials through a nozzle inside the mixer, ensuring reliable fixation of CO_2 in the kneaded materials. Then, secondary kneading is performed to mix the remaining materials with those that underwent primary kneading.

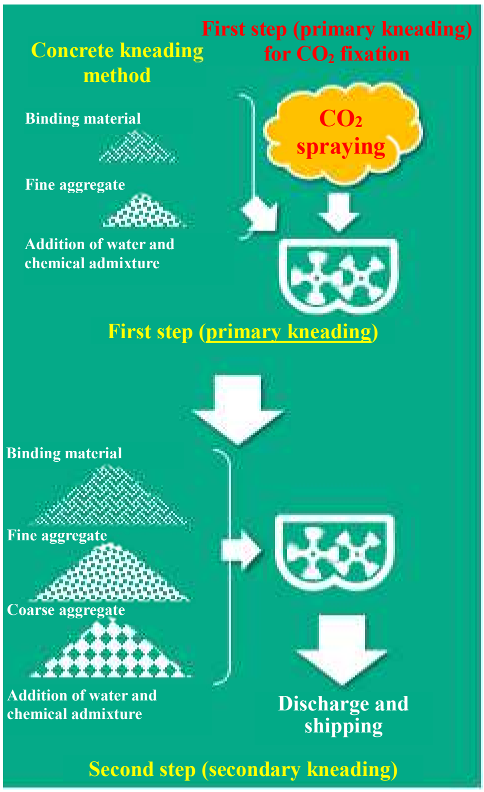
Kneading the concrete in two stages allows for efficient CO_2 fixation by preventing excessive CO_2 fixation.

• Material properties of concrete with CO_2 fixed in it

Concrete with CO_2 fixed in it maintains its internal alkalinity and has strength equivalent to that of ordinary concrete.

• Application to existing facilities

This technology can be applied to existing concrete batching plants by installing cylinders and nozzles for CO_2 spraying at those facilities.

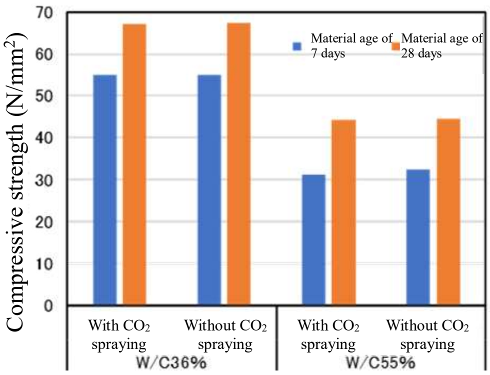


Concrete production procedures[1] with T-Carbon Mixing

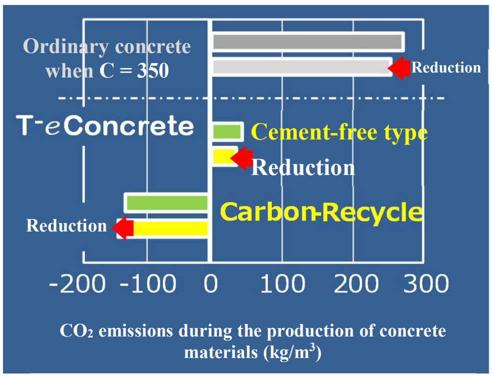
• Combined application with environmentally friendly concrete, T-*e*Concrete®

T-Carbon Mixing can be applied not only to ordinary concrete but also to T-*e*Concrete®* developed by Taisei Corporation for significant reduction in CO_2 emissions.

*T-*e*Concrete® is a type of concrete that can significantly reduce CO_2 emissions during the production of concrete materials. It can be produced and used in the same ways as standard concrete and exhibits performance equivalent to that of standard concrete. By recycling a large quantity of ground granulated blast furnace slag, T-*e*Concrete® contributes to the effective utilization of resources.



Verification results of the effects of CO_2 spraying on concrete compressive strength[1]



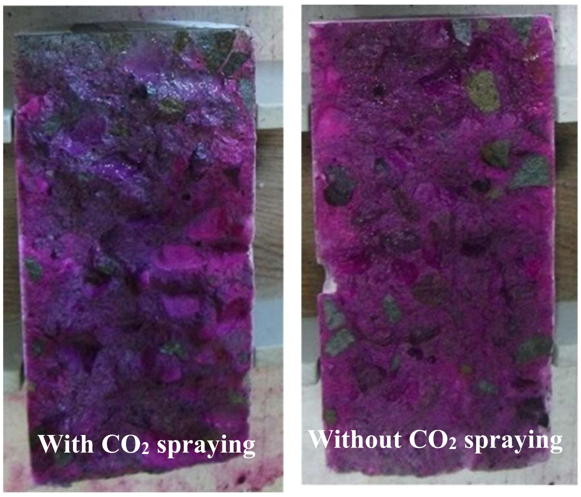
CO_2 emission reduction effects of T-Carbon Mixing

(2) Estimated or actual CO_2 reduction rates

- The CO_2 fixation amount of T-Carbon Mixing is approximately 10 kg/m³, according to laboratory test results using ordinary concrete made with ordinary portland cement and a water-cement ratio of 36% to 55%.[1)]
- T-Carbon Mixing has no effect on the compressive strength of concrete.[1)]
- Concrete with T-Carbon Mixing retains its internal alkalinity.[1)] Therefore, T-Carbon Mixing can be applied to reinforced concrete structures.

Measurement result of CO_2 fixation amount in ordinary concrete[1)]

Test case	CO_2 fixation amount
Water-cement ratio of 36%	10.2 kg/m³
Water-cement ratio of 45%	9.30 kg/m³
Water-cement ratio of 55%	8.20 kg/m³



Result of spraying phenolphthalein onto concrete after secondary kneading, indicating the retention of alkalinity[1)]

(3) Future prospects

This technology can be applied to existing concrete batching plants by installing cylinders and nozzles to spray CO_2 without restricting the types of concrete that can be used. Therefore, we plan to promote this technology throughout the industry for cast-in-place concrete and concrete used in secondary products.

Reference

1) Junichi Matsumoto et al.: "Technology for Fixing CO_2 during Concrete Production," *Concrete Journal*, Vol. 61, No. 2, pp. 138–144, February 2023.

Calcium Carbonate Concrete (CCC) (C^4S Project) by the University of Tokyo and Hokkaido University [9]

(1) Outline of the technology

The C^4S project aims to establish a closed-loop system for concrete resource circulation by developing technologies to combine calcium (Ca) from concrete waste generated during the dismantling of structures with CO_2 from the atmosphere (or high-density CO_2 from factory exhaust gases), and recycling them into calcium carbonate concrete (CCC), with a focus on utilizing Ca from concrete structures as CO_2 absorption sources; and commercializing CCC as a major alternative construction material to conventional cement and concrete.

As of February 2022, the CCC manufacturing processes described in the C^4S project publication included first crushing concrete waste and separating it into recyclable aggregate and fine powder (primarily composed of hardened cement), then fully carbonating them (represented by the chemical reaction: $CaO + CO_2 \rightarrow CaCO_3$), and then, immersing the carbonated fine powder in water while blowing CO_2 into it to produce an aqueous solution of calcium hydrogen carbonate ($Ca(HCO_3)_2$) (represented by the chemical reaction: $CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$). Finally, the aqueous solution of calcium hydrogen carbonate is treated to reduce the solubility of calcium carbonate by passing the solution through recycled aggregate particles packed in a container, evaporating moisture, and adjusting the temperature and pH. This process precipitates fine calcium carbonate crystals in the gaps between the recycled aggregate particles, binding them into a hardened mass.

As of February 2022, the compressive strength, as described in the C^4S project publication, was 15 MPa for a cylindrical specimen with a diameter of 10 mm and 4 MPa for a cylindrical specimen with a diameter of 50 mm. Currently, the manufacturing processes have been improved with the goal of achieving a compressive strength of 12 MPa for a cylindrical specimen with a diameter of 100 mm by the end of 2022. As described above, CCC is expected to significantly reduce CO_2 emissions when used as a replacement for conventional concrete.

(Reprint from the Moonshot C^4S website: https://moonshot-c4s.jp/)

(2) Estimated or actual CO_2 reduction rates

No data on LCA-CO_2 has been published because a detailed examination of the manufacturing processes had not been completed as of October 2023.

(3) Future prospects

As of October 2023, technological development was underway to improve strength and establish manufacturing methods for large members.

T-*e*Concrete series by Taisei Corporation [10], [15], [24] and [26]

(1) Outline of the technology

The CO_2 emissions from manufacturing portland cement account for more than 90% of all CO_2 emissions associated with manufacturing concrete materials. T-*e*Concrete can achieve CO_2 emission reduction and a negative CO_2 balance by replacing a portion of or all cement with industrial byproducts and carbon recycle products. The characteristics of T-*e*Concrete/Carbon-Recycling, which are expected to contribute to the decarbonization of society, are summarized below.

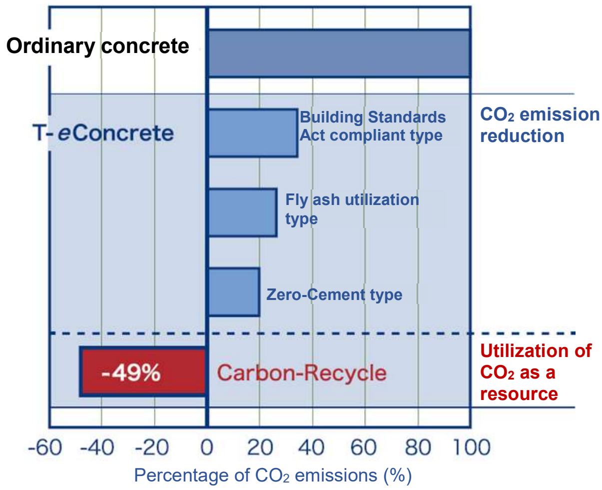
T-eConcrete® Series, environmentally friendly concrete

● **Building Standards Act compliant type**
This type uses blast furnace slag (an industrial byproduct generated in the steelmaking processes) in place of cement and is suitable for building construction.

● **Fly ash utilization type**
This type uses blast furnace slag and fly ash (a type of coal ash) in place of cement and is suitable for concrete used in areas near power plants and other facilities where coal ash is readily available.

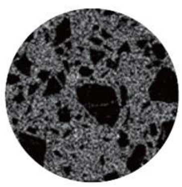
● **Zero-Cement type**
This type solidifies blast furnace slag with a special reactant without using cement and produces concrete for optimal CO_2 emission reduction.

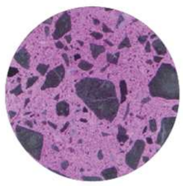
● **Carbon-Recycling**
This is a type of concrete produced by adding carbon recycle products such as calcium carbonate to T-eConcrete/Zero-Cement.
This type of concrete can achieve a negative CO_2 balance and aims to establish a recycling system by 2030.



Technical features


Cross section (10-cm diameter)


Distribution of fixed carbon (white dots)


Coloration with a pH indicator (pink indicates strong alkalinity)

● **T-eConcrete® can realize a negative CO_2 balance**
T-eConcrete uses industrial byproducts (such as blast furnace slag) that generate minimal CO_2 emissions while fixing a large quantity of CO_2 as calcium carbonate.

	CO_2 emission (balance)	CO_2 fixation as calcium
Track record*	−116 ～ −45kg/m³	98 ～ 171kg/m³
Experiment value	−55 ～ −5kg/m³	70 ～ 170kg/m³

***Technological development has improved CO_2 fixation compared to experiment values.**

● **T-eConcrete® can enhance the durability of structures by preventing the corrosion of reinforcing bars**
- T-eConcrete® exhibits strong alkalinity as it fixes CO_2 by forming calcium carbonate without directly absorbing CO_2.
- T-eConcrete® maintains the durability of structures by preventing the corrosion of reinforcing bars and allows conventional structures to be constructed.

● **T-eConcrete® can be produced using standard facilities and it demonstrates strength and workability equivalent to that of conventional concrete**
- T-eConcrete® can be produced with standard facilities of ready-mix concrete factories.
- T-eConcrete® can ensure safety by keeping CO_2 gas away from construction sites.
- T-eConcrete® has a slump of 12 to 21 cm, a slump flow of 45 to 60 cm and compressive strength of 20 to 45 N/mm_2.


Slump of 15 cm


Slump flow of 60 cm


Compressive strength of 20 to 45 N/mm^2

(2) Estimated or actual CO_2 reduction rates

⁎ Examples of facilities using T-*e*Concrete/Carbon-Recycling and CO_2 reduction rate

○ Cast-in-place concrete pavement and pavement blocks in front of the Human Space Lab of the Taisei Advanced Center of Technology

Using T-*e*Concrete/Carbon-Recycling for cast-in-place concrete pavement and pavement blocks contributed to a reduction in CO_2 emissions of more than 1.5 tons.

Construction date: December 2021

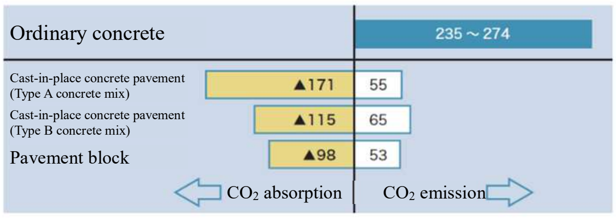
Constructed area:

Cast-in-place concrete pavement

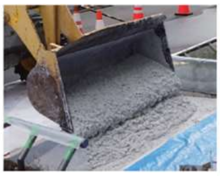
- Type A concrete mix (compressive strength of 25.5 N/mm^2): 3.84 m^2
- Type B concrete mix (compressive strength of 43.8 N/mm^2): 3.84 m^2

Pavement block: 69.5 m^2

Area in front of the Human Space Lab of the Taisei Advanced Center of Technology



Balance of CO2 emissions during concrete production (unit: kg/m^3)



Cast-in-place concrete pavement work

Pavement block work

○ Wall members for the Acoustics Lab of the Taisei Advanced Center of Technology

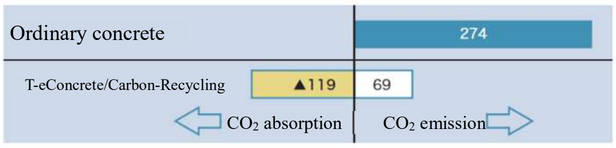
Using T-*e*Concrete/Carbon-Recycling for wall members contributed to a reduction in CO_2 emissions of more than 1.1 tons.

Construction date: November 2021

Constructed area: 28.8 m^2

Concrete specifications:

- Dimensions: 3 m × 0.6 m × 0.12 m • Quantity: 12 pieces
- Compressive strength: 40 N/mm^2
- Reinforcing materials: reinforcing bar and steel fiber



Balance of CO2 emissions during concrete production (unit: kg/m^3)

Acoustics Lab of the Taisei Advanced Center of Technology

* Example of facilities using T-*e*Concrete/Zero-Cement and CO_2 reduction rate

○ Shield tunnel construction for sewage treatment plant

The country's first application of T-*e*Concrete/Zero-Cement, which does not use cement, to a shield tunnel. T-*e*Concrete/Zero-Cement contributed to a reduction in CO_2 emissions by more than 70% compared to the use of conventional segments.

○ Cave road construction in the Inzai Area of Chiba Prefecture (Part 2)

A large quantity of T-*e*Concrete/Zero-Cement was used for the invert section of the cave road for underground power transmission for which a shield tunneling method was used.

T-*e*Concrete/Zero-Cement contributed to a reduction in CO_2 emissions by about 80% compared to the manufacture of conventional concrete. The CO_2 reduction rate was equivalent to a reduction of 53.8 tons for the invert and pedestrian floor members combined based on the usage of 223 m³ of T-*e*Concrete/Zero-Cement.

(3) Future prospects

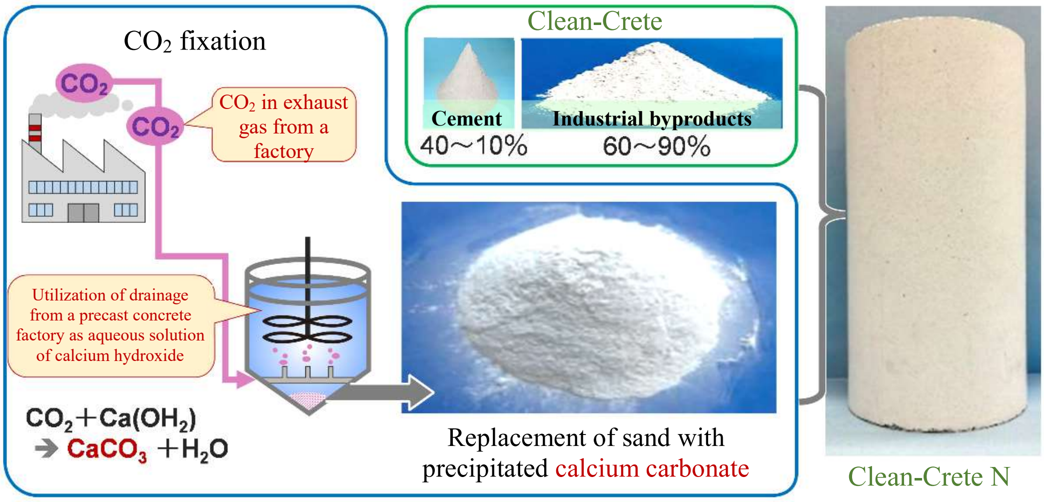
All four types of T-*e*Concrete can be manufactured using existing equipment and facilities, making it suitable for cast-in-place concrete in RC structures, thereby facilitating the replacement of conventional concrete. Additionally, the T-*e*Concrete series has steadily accumulated a track record. We will proactively promote the social implementation of T-*e*Concrete in cast-in-place concrete and secondary concrete products.

Clean-Crete N by Obayashi Corporation [11]

(1) Outline of the technology

Clean-Crete N is a type of concrete that can achieve not only carbon neutrality (a zero balance in CO_2 emissions) but also carbon negativity (a negative balance in CO_2 emissions) by mixing Clean-Crete* with carbon dioxide capture and utilization (CCU) powder. CCU powder is primarily made of calcium carbonate produced by introducing exhaust gas generated during steam curing at a production factory of centrifugally molded concrete products into sludge water discharge from the factory. Clean-Crete N has a CO_2 fixation amount of 390 kg-CO_2/ton and can simultaneously reduce CO_2 emissions and waste generation.

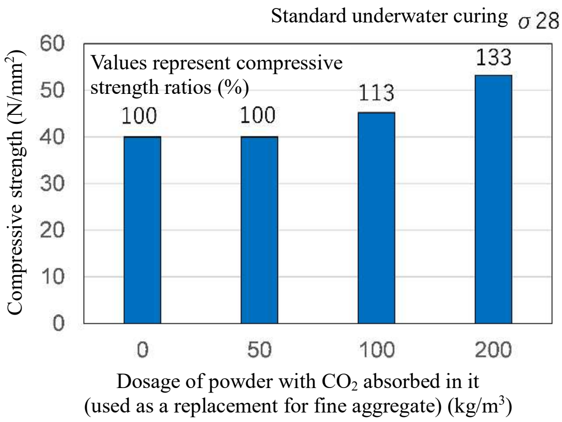
*Clean-Crete is a type of low-carbon concrete that replaces a significant amount of cement with industrial byproducts (admixtures) such as ground granulated blast furnace slag, fly ash, and silica fume, reducing CO_2 emissions by 70% to 80% compared to conventional concrete that uses cement.



Outline of Clean-Crete N

Clean-Crete N is particularly suitable for high-fluidity concrete, as it is composed of a large amount of fine materials, including cement, ground granulated blast furnace slag, and CCU powder. Requiring no compaction, Clean-Crete N can reduce labor at construction sites. It has been confirmed that the compressive strength of Clean-Crete N increases with higher dosage of CCU powder.

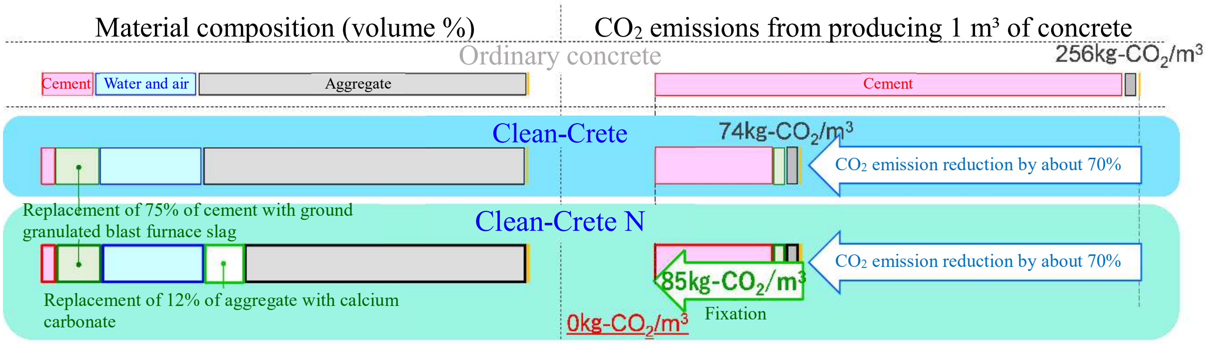
Fresh properties Clean-Crete N



Relationship between the dosage of CCU powder and compressive strength

(2) Estimated or actual CO_2 reduction rates

In the standard mix of Clean-Crete, 75% of portland cement, which has a CO_2 emission rate of 760 to 770 kg-CO_2/ton, is replaced with ground granulated blast furnace slag (24 to 36 kg-CO_2/ton), leading to a CO_2 emission reduction of about 70%. In the mix of Clean-Crete N, fine aggregate is further replaced with CCU powder. The dosage of CCU powder is variable. To achieve carbon neutrality, an example dosage is 200 to 250 kg per cubic meter of Clean-Crete N, balancing CO_2 emissions with CO_2 absorption. Additionally, increasing the proportion of CCU powder can further enhance CO_2 emission reduction, achieving carbon negativity. In March 2023, Clean-Crete N was used for a cast-in-place retaining wall and reduced 106% of CO_2 emission compared to conventional concrete.



CO_2 emission reduction by Clean-Crete N

(3) Future prospects

Since no standards have been established for CCU powder, it is difficult to apply Clean-Crete N to main structural members subject to the Building Standards Act (and Clean-Crete N is also not covered by JIS). Therefore, experiments to verify its quality have been in progress to prepare to expand its applicability and establish standards.

Experimental facility of Obayashi Corporation in which the external precast wall members made with Clean-Crete N are planned to be used

Although Clean-Crete has attracted attention and met customer needs, there is currently an insufficient number of CCU powder manufacturing bases and an inadequate supply of CCU powder. Therefore, inter-industrial collaboration is essential for strengthening the manufacturing and supply capacity of CCU powder in the future. Additionally, standards need to be established for manufacturing bases once they are expanded to multiple locations.

SUSMICS-C by Shimizu Corporation [12]

(1) Outline of the technology

SUSMICS-C is a type of environmentally friendly concrete that stores carbon in concrete structures by incorporating biochar, produced through the carbonization of woody biomass, into the concrete mix. This technology utilizes timber-derived biochar that has absorbed CO_2 from the atmosphere during the growth of the trees, thereby fixing CO_2 in the concrete. When combined with low-carbon cement in place of some of the cement generating a large amount of CO_2 during its production with blast furnace slag, SUSMICS-C can realize carbon negativity where the amount of CO_2 fixed exceeds the CO_2 emissions.

Biochar is produced through carbonization, an incomplete combustion process of biomass raw materials. Timber-derived biochar contains fixed CO_2 that trees absorbed through photosynthesis, stored as carbon. In the agricultural sector, the application of biochar to farmland has been certified as eligible for the government J-Credit Scheme, meaning that the amount of CO_2 stored is recognized as an environmental value.

SUSMICS-C has undergone tests to obtain basic data, including fresh properties, curing characteristics, durability, trial mixing using an actual mixer and a pumping test at a concrete batching plant, all with respect to a general concrete mix for civil engineering use with a design strength of 24 N/mm². As shown in Figures 11.1 and 11.2, it has been confirmed that SUSMICS-C has workability and quality equivalent to those of ordinary concrete.

SUSMICS-C is characterized by the following factors. First, it is versatile, as it can be applied to secondary concrete products and produced at a batching plant for delivery to construction sites. Second, it is efficient in fixing CO_2, with 1 kg of concrete capturing CO_2 at a rate four times higher than concrete using calcium carbonate. Third, it offers the potential for carbon neutrality and negativity when combined with low-carbon cement, such as Type B or C blast furnace cement.

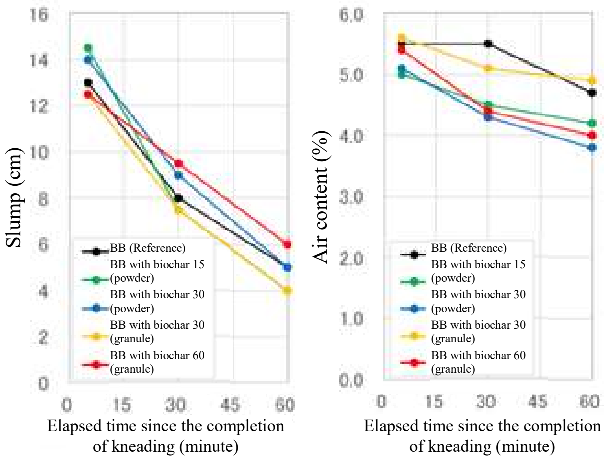


Figure 11.1 Slump and air content

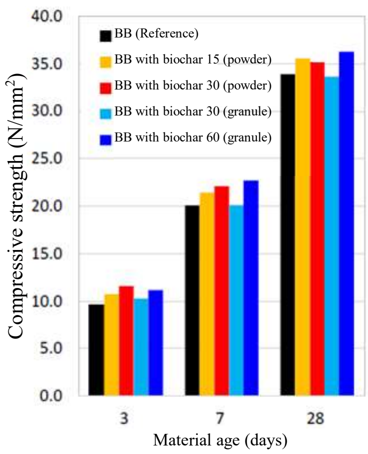


Figure 11.2 Compressive strength

(2) Estimated or actual CO_2 reduction rates

Biochar is produced from sawdust generated during the lumbering of both softwood and hardwood trees. Compared to other types of biochar, the biochar obtained through the carbonization of sawdust is characterized by its ability to stably fix a large amount of carbon, achieving a carbon content of approximately 90%. According to the methodology for farmland application in the J-Credit Scheme, the carbon residual rate after 100 years is approximately 90%. Since 1 kg of biochar fixes 2.3 kg of CO_2, mixing 60 kg of biochar per cubic meter of concrete can fix 137 kg of CO_2. As shown in Table 11.1, carbon neutrality can be achieved by mixing biochar with Type B blast furnace cement at a rate of 60 kg/m³ or with Type C blast furnace cement at a rate of 40 kg/m³ in a concrete mix of 24-12-20N. Additionally, carbon negativity can be attained by mixing biochar with Type B blast furnace cement at a rate of 80 kg/m³ or with Type C blast furnace cement at a rate of 60 kg/m³.

In October 2022, as the first case of applying SUSMICS-C to actual construction, 34.5 m³ of SUSMICS-C, which included a mixture of biochar with Type B blast furnace cement at a rate of 60 kg/m³, was used for the temporary concrete pavement of a temporary road within a construction site. In this application, SUSMICS-C achieved a 99% reduction in CO_2 emissions compared to ordinary concrete, equivalent to a reduction of 6.7 tons of CO_2.

Table 11.1 Example of the calculation of CO_2 emission reduction effect of SUSMICS-C

ID code	Type of cement	Dosage of biochar	CO_2 reduction due to low-carbon cement*1 A	CO_2 fixation due to biochar B	CO_2 emission reduction per m³ A+B	CO_2 reduction rate per m³*2
N-powder 20	Ordinary portland cement	20 kg/m³	0 kg/m³	46 kg/m³	46 kg/m³	19% reduction
BB-powder 20	Type B blast furnace cement	20 kg/m³	97 kg/m³	46 kg/m³	143 kg/m³	60% reduction
BB-granule 60		60 kg/m³		137 kg/m³	234 kg/m³	99% reduction
BB-granule 80		80 kg/m³		183 kg/m³	280 kg/m³	118% reduction
BC-granule 40	Type C blast furnace cement	40 kg/m³	143 kg/m³	91 kg/m³	234 kg/m³	99% reduction
BC-granule 60		60 kg/m³		137 kg/m³	280 kg/m³	118% reduction

*1: With respect to concrete mix of 24-12-20N using ordinary portland cement

*2: With respect to concrete mix of 24-12-20N for CO_2 emission reduction of 238 kg/m³

(3) Future prospects

SUSMICS-C is versatile and enables CO_2 fixation to be quantitatively assessed. Therefore, we will promote the widespread use of SUSMICS-C not only in civil engineering but also in the building sector as environmentally friendly concrete. In the building sector, a minister's certificate is required when using SUSMICS-C for structural members as it has not been standardized by JIS. However, it can be applied to nonstructural members without a certificate. Therefore, the first step under consideration is to expand the application of SUSMICS-C to nonstructural members. Additionally, we aim to apply biochar widely to construction materials beyond concrete, such as ground improvement materials and greening base materials, thereby contributing to CO_2 emission reduction during construction across broader areas.

LigninCrete by Obayashi Corporation [13]

(1) Outline of the technology

Wood accumulates CO_2 by absorbing it through photosynthesis during the growth of trees. Using wood has gained attention from the perspective of a circular economy, where wood is used, replanted, and grown. Fixing CO_2 by using wood contributes to the fight against global warming, which raises expectations for the proactive use of wood.

Incorporating lignin, a type of woody biomass (renewable organic resources derived from living organisms excluding fossil fuels) that is discharged from the papermaking process using wood as a raw material and that releases CO_2 into the atmosphere when decayed or combusted, LigninCrete can fix a large amount of CO_2 in concrete for an extended period of time. One kilogram of lignin has absorbed 2.4 kg of CO_2.[*1] Adding lignin to concrete at a rate of 100 kg/m³ results in approximately 240 kg of CO_2 being fixed in the concrete. By additionally incorporating industrial byproducts, LigninCrete can balance the amount of CO_2 it fixes with that released during the production of fresh concrete. Therefore, using LigninCrete can contribute to realizing environmental circulation and a decarbonized society.

*1: The value was estimated based on the carbon content of lignin powder analyzed after fully vaporizing the moisture.

Woody biomass (lignin powder)

Slump property of LigninCrete

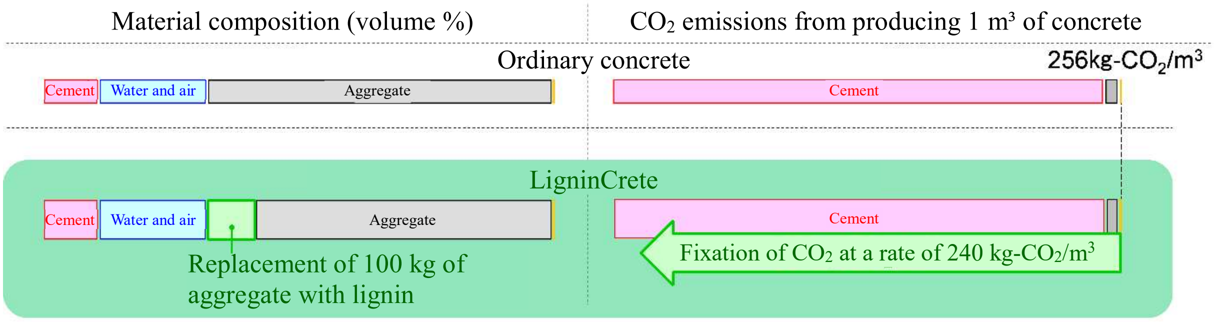
Being powdery, lignin can be added to fresh concrete and mortar to ensure appropriate workability when used with a special admixture. After casting, lignin does not require special curing and can contribute to the practical strength and durability of the concrete. Additionally, LigninCrete replaces part of the sand with lignin, reducing the amount of sand used and contributing to the preservation of natural resources. When dismantled, LigninCrete can be used as recycled aggregate with CO_2 still fixed in it. Therefore, LigninCrete can fix CO_2 semi-permanently.

Ordinary concrete (left), LigninCrete (right)

Cross section of a LigninCrete specimen after curing

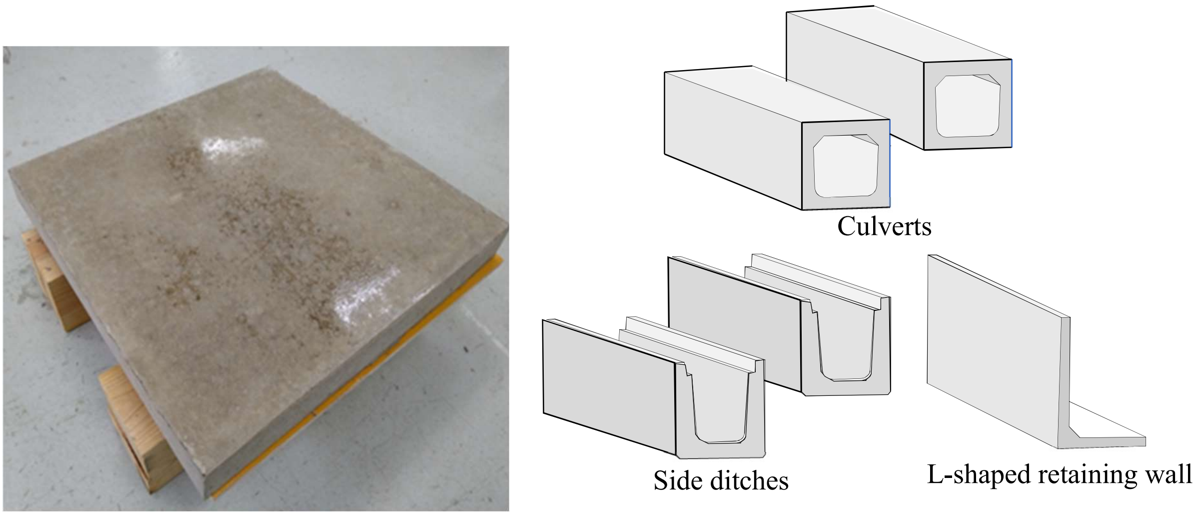
(2) Estimated or actual CO_2 reduction rates

LigninCrete enables lignin to be added to concrete at a rate of up to 100 kg/m^3, resulting in CO_2 fixation of about 240 kg/m^3. As a result, LigninCrete can fix nearly the same amount of CO_2 as is emitted during the production of concrete. Additionally, LigninCrete can further reduce CO_2 emissions and contribute to carbon negativity by using Type B blast furnace cement or by replacing part of the cement with industrial byproducts.



(3) Future prospects

In the construction sector, cement and concrete, like steel, are major contributors to CO_2 emissions. This technology, which focuses on lignin from woody biomass, is expected to help fix CO_2 in concrete for an extended period, serving as a climate change mitigation measure. Additionally, despite the addition of lignin to concrete, LigninCrete is expected to demonstrate durability equivalent to that of conventional concrete. LigninCrete is planned to be widely used not only in concrete products like blocks but also in cast-in-place concrete in the future.



Precast LigninCrete slab

Concrete products to which LigninCrete can be applied

ECM Concrete by Kajima Corporation [14]

(1) Outline

ECM® (Energy, CO_2, Minimum) concrete is a type of concrete made using ECM cement. ECM cement is a material that has achieved both durability and reduction in environmental impact by replacing substantial amount of cement in with ground granulated blast furnace slag an industrial by-product. ECM cement, which can be classified as Type C blast furnace cement (in accordance with JIS standards), was jointly developed by one university and seven companies, namely Takenaka Corporation, Kajima Corporation, DC Co., Ltd., Nippon Steel Blast Furnace Slag Cement Co., Ltd., Tokyo Institute of Technology, Taiheiyo Cement Corporation, Nippon Steel Cement Co., Ltd., and Takemoto Oil & Fat Co. Ltd.

[1] Replacing cement with ground granulated blast furnace slag

In ECM cement, a major proportion of cement, typically 60 to 70% is replaced with ground granulated blast furnace slag. This replacement allows it to be used as Type C blast furnace cement (as per JIS standards). However, conventional concrete made with Type C blast furnace cement has some drawbacks such as significant slump loss, low initial strength, and substantial shrinkage. In contrast, ECM concrete has overcome these challenges by improving the cement composition, and use of special air-entraining (AE) and water-reducing agents. This facilitates ECM cement to be applied as a replacement for Type B blast furnace cement with similar properties despite having a much higher content of blast furnace slag. Also, compared to concrete made with moderate heat cement, the advantage of using ECM cement is that it has a much smaller carbon footprint.

[2] Excellent thermal cracking resistance and economic viability

The high proportion of blast furnace slag in ECM cement results in reduced heat generation during hydration, making it highly resistant to thermal cracking and hence optimal for mass concrete applications and potential application for cast-in-place concrete piles. Compared to conventional concrete, ECM concrete demonstrates a reduction in adiabatic temperature rise by approximately 10 degrees Celsius, thereby effectively suppressing thermal cracking.

Figure 13.1 ECM cement

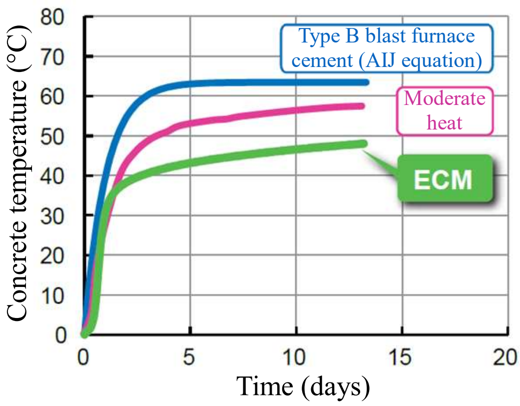


Figure 13.2 Adiabatic temperature rise in concrete

(2) Amount of Reduction in CO_2 emission and Application

[1] Reduction in CO_2 emission by ECM cement

Figure 13.3 illustrates a comparison of CO_2 emissions between concrete made with ECM cement and that made with conventional moderate heat cement. ECM cement can achieve an approximately 60% reduction in CO_2 emissions compared to conventional moderate heat cement due to the replacement of a significant portion of the cement with ground granulated blast furnace slag an industrial by-product.

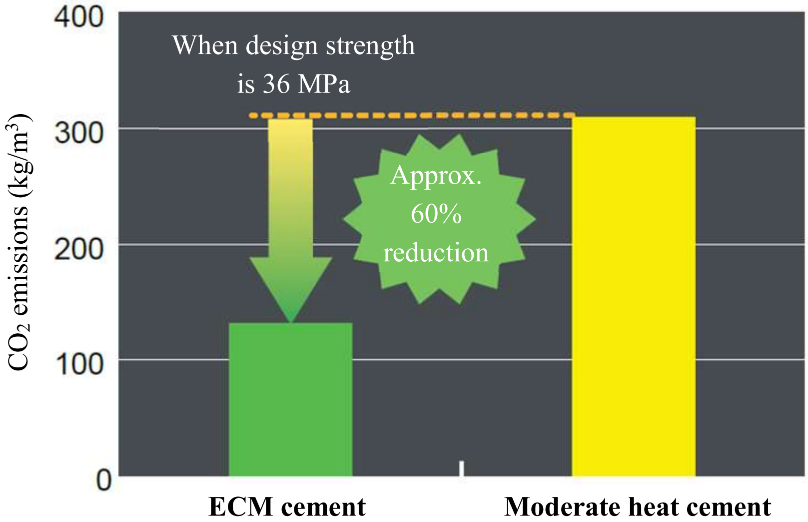


Figure 13.3 Comparison of CO_2 emissions between ECM cement and moderate heat cement

[2] Application of ECM concrete

ECM concrete can be supplied to Tokyo, Osaka, Kyoto, Kitakyushu etc. Until now it has been successfully applied to build underground mass concrete structures and marine port facilities, with a total volume of approximately 380,000 m^3.

- Offices
- Hotels
- Incineration facilities
- Marine port facilities, and others

(3) Future prospects

ECM concrete offers multiple benefits, such as reducing CO_2 emissions and providing high durability, while also exhibiting excellent resistance to thermal cracking. Additionally, due to its low heat of hydration, ECM concrete is suitable for constructing mass concrete structures with large cross-sections. While ECM concrete is currently available in major cities, its supply range is limited. Currently, efforts are being made to expand its application across the nation and increase its applicability to civil engineering structures such as dams etc.

Super Green Concrete by Maeda Corporation [16]

(1) Outline of the technology

Super Green Concrete (SG Concrete) is a type of low-carbon concrete made entirely or partially with portland cement, ground granulated blast furnace slag, fly ash, silica fume, and gypsum. In SG Concrete, the ratio of portland cement to binding materials is less than 30%, which is lower than that of cement conforming to JIS standards, and the proportion of admixtures exceeds 70%. Thus, SG Concrete can lower carbon dioxide emissions from its materials to 20 to 40% of those from general concrete, achieving a reduction rate of 60 to 80%.

SG Concrete can be used for structures requiring a design strength of 18 to 36 N/mm² and is intended for cast-in-place concrete work. Since SG Concrete has low endothermic properties and is resistant to chloride ion infiltration, it can be effectively used for mass concrete structures and in environments subject to salt damage. Additionally, SG Concrete is expected to be an effective means of suppressing alkali-silica reactions. On the other hand, SG Concrete, which uses a small amount of cement, is less resistant to neutralization than general concrete.

SG Concrete was developed in collaboration with Taisei Corporation as part of the "Research on Utilization Technologies of Low-Carbon Cement Binders," a joint research project led by the Public Works Research Institute. SG Concrete meets the application criteria outlined in *Recommendations for Design and Construction of Concrete Structures Containing High-volume Mineral Admixtures*, Concrete Library Vol. 152, published by the Japan Society of Civil Engineers.

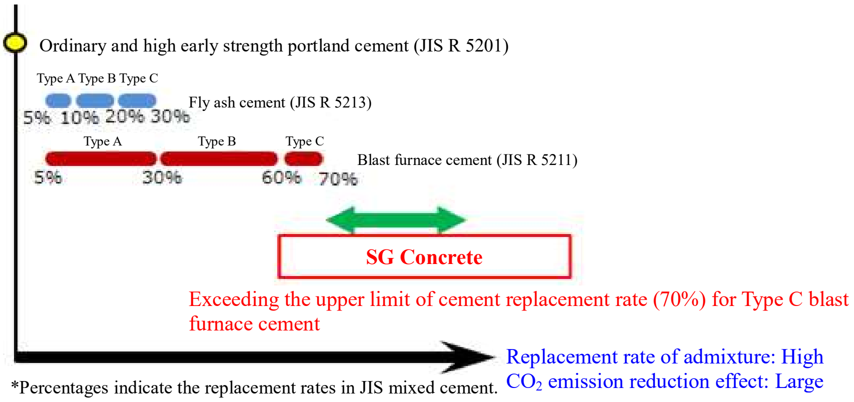


Figure 15.1 Positioning of the binding material of SG Concrete

(2) Estimated or actual CO_2 reduction rates

Figure 15.2 shows CO_2 emission reductions per m³ of concrete for typical mixes of H25BF (with binding material proportions of 25% cement, 45% ground granulated blast furnace slag, and 30% fly ash) and H10BS (with binding material proportions of 10% cement, 85% ground granulated blast furnace slag, and 5% silica fume). These mixes were designed for concrete with a nominal strength of 24 (at 28 days). Compared to general concrete made with only ordinary portland cement at a water-cement ratio of 55%, H25BF and H10BS can reduce CO_2 emissions by 61% and 81%, respectively.

The track record of SG Concrete includes the floor slabs of a research institute. In this case, 68 m^3 of SG Concrete was produced at a batching plant in a city and shipped to a construction site (see Figure 15.3).

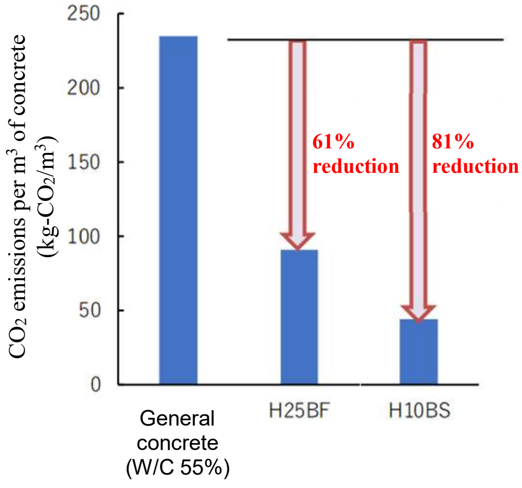


Figure 15.2 CO_2 emissions from SG Concrete

Low-carbon concrete

Casting low-carbon concrete

Finishing low-carbon concrete

After finishing low-carbon concrete

Figure 15.3 Example of construction works using SG Concrete

(3) Future prospects

Developing concrete that contributes to carbon neutrality requires measures to ensure reliability, including establishing design methods for durability and other performance variables, standardizing evaluation methods for CO_2 emission reductions, implementing a third-party certification system, and providing incentives. Future challenges include procuring admixtures with consideration for environmental impact and costs, as well as selecting production factories. To address these challenges, it is necessary to pursue efforts involving the entire construction sector.

LHC (Low-carbon High-performance Concrete) by Hazama Ando Corporation [17]

(1) Outline of the technology

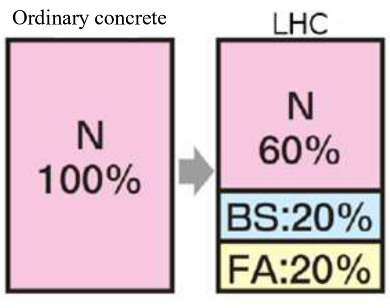
- Three-component system concrete blended with ordinary portland cement (N), ground granulated blast furnace slag (BS) and Type II fly ash (FA) at a ratio of 6:2:2.
- LHC can be practically produced at batching plants by blending N, Type B blast furnace cement (BB) and FA, and shipped.
- Nominal strength and slump are within the ranges specified in JIS A 5308.
- LHC can be produced, used in construction, and undergo quality control just like general concrete. Additionally, LHC enhances pumpability.
- Being low in heat generation, LHC helps to suppress thermal cracking (LHC > BB > N).
- When using a water-binding material ratio of 55%, although LHC shows lower initial strength than concrete made with ordinary portland cement, it meets the required demolding strength of 5 N/mm² on vertical planes at a material age of 3 days. LHC also achieves higher long-term strength than concrete with ordinary portland cement at a material age of 56 days.
- Patent No. 6177534
- LHC is not subject to specific constraints in use if it meets the required ranges for nominal strength and slump, and if it has no issues with strength development.

(2) Estimated or actual CO_2 reduction rates

- CO_2 reduction rate of approximately 45% (compared to concrete made with ordinary portland cement)

(3) Future prospects

- This technology enhances the performance of Type B blast furnace cement (BB). We will proactively expand the applications of LHC as we have done before.



Composition ratios of binding materials

Casting LHC in Apporo Dam Closure Work

BBFA High Strength Concrete by Hazama Ando Corporation [18]

(1) Outline of the technology

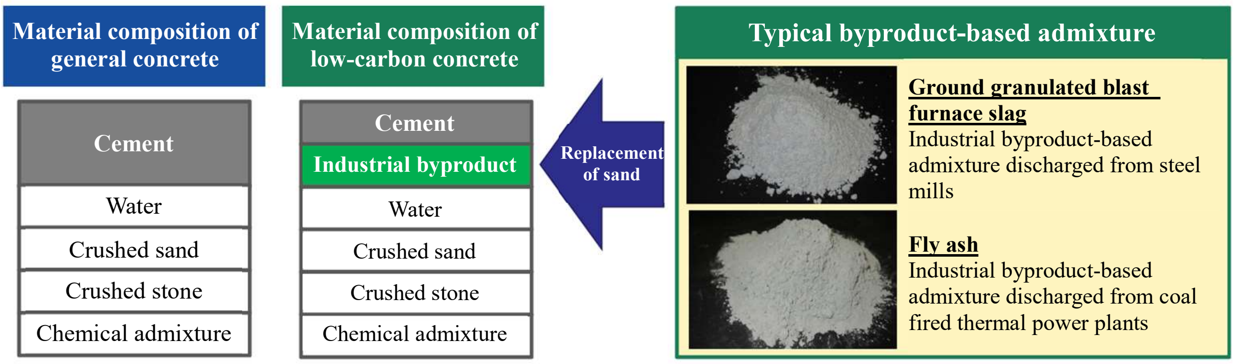
- BBFA High Strength Concrete is a type of concrete blended with Type B blast furnace cement (BB) and Type II fly ash (FA) at a ratio of 8:2.
- The range of nominal strength is 46 to 73, slump is 18 to 23 cm and slump flow is 50 to 65 cm, some of which are outside the ranges specified in JIS A 5308.
- Being low in heat generation, BBFA High Strength Concrete helps to suppress thermal cracking (BBFA > BB > N).
- BBFA High Strength Concrete can be produced, used in construction, and undergo quality control just like general concrete.
- BBFA High Strength Concrete is not subject to any constraints in particular if it meets the required ranges for nominal strength and slump, and if it has no issues with strength development."

(2) Estimated or actual CO_2 reduction rates

- CO_2 reduction rate of approximately 50% compared to concrete made with ordinary portland cement

(3) Future prospects

- A ministerial certificate has been obtained for BBFA High Strength Concrete in collaboration with batching plants to ensure quality. Therefore, we will further expand the technological applications of BBFA High Strength Concrete by increasing the number of applicable batching plants in the future.
  → Batching plants with the ministerial certificate: 2 plants in the metropolitan area and 3 in Sendai area



Ashcrete by Hazama Ando Corporation [19]

(1) Outline of the technology

- A hardened body primarily composed of coal ash in raw powder form, mixed with water (seawater) and cement (N and BB).
- Ashcrete uses the minimum amount of water required and is liquefied by being vibrated (super-fluidization method).
- For Ashcrete used onshore, the dosage of gypsum is adjusted to prevent harmful elements from leaching out.
- The specific gravity of Ashcrete can be adjusted by incorporating metal slag.
- In offshore areas, Ashcrete has been used for artificial submarine mountain ranges and wave-dissipating blocks.
- In onshore areas, Ashcrete has been used for embankment construction and roadbed materials.
- There is a risk that harmful elements, such as hexavalent chromium, arsenic, selenium, fluorine, and boron, could leach out from Ashcrete.
- Given that countermeasures have already been implemented to prevent harmful elements from leaching out by adjusting the materials used and their mixtures, Ashcrete can be safely used in offshore areas where there is little risk from harmful elements leaching out and as a material for embankment construction. However, caution is required for specific applications.
- Overall, 1.7 million tons of coal ash in raw powder form have been used.

(2) Estimated or actual CO_2 reduction rates

- CO_2 reduction rate of approximately 40% (compared to concrete having a compressive strength of 30 N/mm^2)
- Utilization of waste: 1,000 to 1,200 kg/m^3 of coal ash in raw powder form (depending on target strength)

(3) Future prospects

- Efforts to expand the application of Ashcrete in onshore areas will continue, as we begin to explore possible expansion into offshore areas.
- Application of ash from sources other than coal, such as biomass ash, has been planned to support the broader technological expansion of Ashcrete for carbon neutrality.



Ashcrete production and crushed materials

Geopolymer (Geopoly) by Nishimatsu Construction Co., Ltd. [20]

(1) Outline of the technology

Geopolymer is a collective term for amorphous polymers produced through the reaction of silica alumina powder with alkaline-silica solution as proposed by Davidovits in France in 1988. In the concrete sector, sodium silicate solution or sodium hydroxide is often used as an alkaline-silica solution, and fly ash or ground granulated blast furnace slag is commonly used as an active filler.

CO_2 emissions during the production of geopolymer materials are lower than those of cement. It is estimated that using geopolymers in the construction of structures can reduce CO_2 emissions by up to 80% compared to using cement. Thus, geopolymers have the potential to be the next generation binder for concrete. In addition to fly ash and ground granulated blast furnace slag, granulated molten slag from municipal solid waste or sewage sludge can also be used as an active filler. Therefore, this technology is excellent for the effective utilization of industrial byproducts.

Regarding the component elements, geopolymers have higher Na and K contents compared to Ca in cement concrete. This difference results in geopolymers having solidified substance properties that are very different from those of cement concrete. For example, numerous reports indicate that geopolymers are superior to cement in terms of resistance to acidity and heat. Additionally, geopolymers are expected to suppress cracking due to alkaline aggregate reaction.

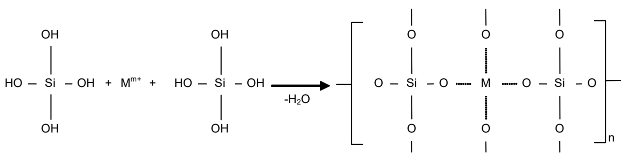
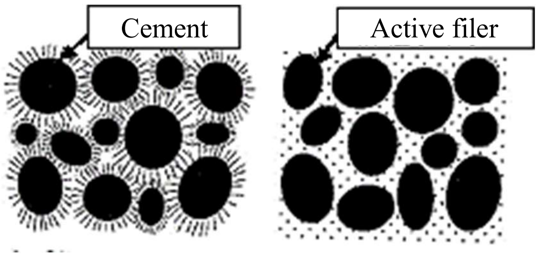


Figure 19.1 Schematic diagram of solidified geopolymer



(a) Cement (b) Geopolymer

Figure 19.2 Conceptual image of solidified form

(2) Estimated or actual CO_2 reduction rates

The following is an estimate of the CO_2 reduction rate of geopolymers. The cement concrete mixture used in the estimation is the same as that used by manufacturers of secondary concrete products.

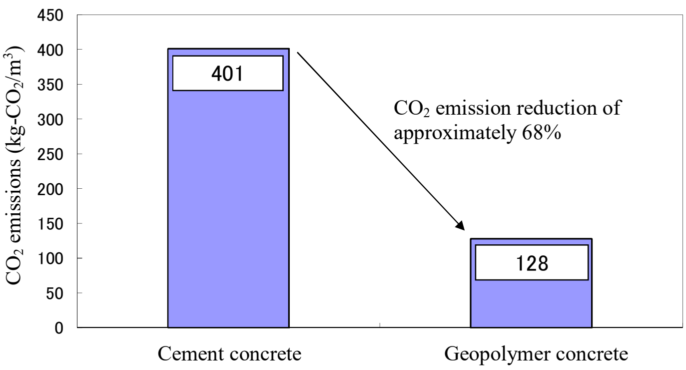


Figure 19.3 CO_2 reduction rates

There are numerous examples of construction using geopolymers, including experimental projects. Photo 19.1 shows curb blocks made with a geopolymer used in the "Improvement Work for Prefectural Road No.

3, 2015 Prefectural Independent Road Improvement Project" commissioned by Oita Prefecture. As of April 2023, more than 150 blocks have been installed, covering a total length of over 100 meters.

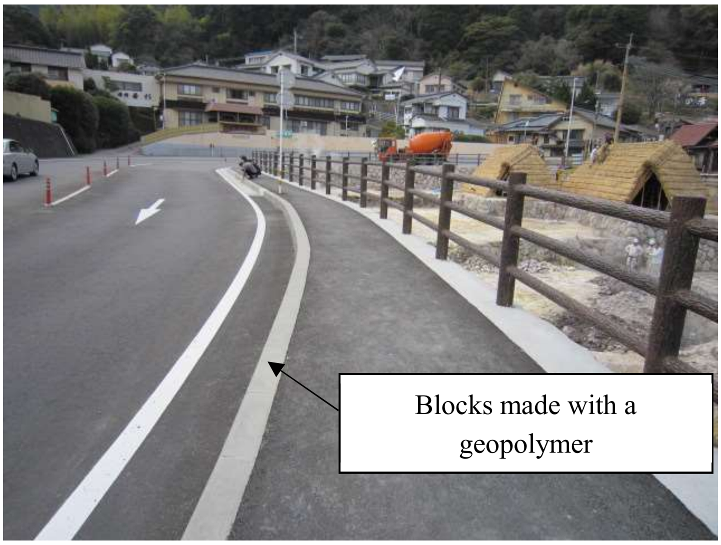


Photo 19.1 Installation example

(3) Future prospects

As a leading company in geopolymer technology, we have spearheaded the research and development of geopolymer technologies. Our leadership has led to the development of geopolymers by numerous research institutes and private companies. As with the development and commercialization of cement, new materials cannot be brought to market without collaborative research and development efforts by numerous organizations. We have high expectations for the development of geopolymers in the future.

In contrast, we have conducted research on geopolymers using biomass ash discharged from biomass power plants, which are expected to be constructed in many other locations in the future, under the ERCA subsidy project. We plan to obtain research results by the end of 2023. Additionally, focusing on the potential of geopolymer materials as an industrial byproduct that can be utilized in the local market, we have been developing “Ryukyu Geopolymer” in collaboration with local companies and a university, with funding from Okinawa TLO since 2022.

AAM Concrete by Nishimatsu Construction Co., Ltd. [21]

(1) Outline of the technology

AAM (Alkali Activated Materials) Concrete is an environmentally friendly type of concrete that uses a byproduct, such as blast furnace slag discharged from steel mills, either as a powder or fine aggregate. This concrete undergoes solidification through the reaction of the slag with an alkali solution. AAM Concrete was developed jointly by Nishimatsu Construction Co., Ltd., JFE Steel Corporation, Tohoku University, and Nihon University as a construction material that excels in strength development and resistance to frost damage, while also being suitable for field work and application to secondary products.

[1] Utilization of industrial byproducts

By using blast furnace slag, which is an industrial byproduct that generates much less CO_2 emissions compared to the production of portland cement, as concrete materials (powder and fine aggregate), AAM Concrete can reduce CO_2 emissions during its production relative to ordinary concrete.

[2] Production and transportation

As is the case with ordinary concrete, AAM Concrete can be produced with general concrete mixers and transported with agitator trucks.

[3] Cast-in-place construction

Our extensive knowledge of mix design allows us to ensure the fluidity and resistance to material segregation of AAM Concrete, making it suitable for site work while allowing adjustments to the pot life based on site conditions. Thus, AAM Concrete enhances the productivity of construction sites. Additionally, AAM Concrete excels in strength development at ordinary ambient temperatures, ensuring a compressive strength of more 10 N/mm² on day 1 and 30 N/mm² on day 28.

Photo 20.1 Confirmation of fresh properties

Photo 20.2 Confirmation of fluidity and filling properties on earthen floor

[4] Frost damage resistant properties

Assuming combined deterioration due to salt and frost damage from the use of antifreeze agents in cold regions, a freeze-thaw test was conducted by immersing specimens in saltwater. The test confirmed that AAM Concrete has the required freeze-thaw resistance.

(2) Amount of CO_2 emission reduction and track record

[1] CO_2 emission reduction by AAM Concrete

The figure on the right shows CO_2 emission reductions during the production of ordinary concrete and AAM concrete, both with a nominal strength class of 24. By using blast furnace slag, an industrial byproduct, as powder and fine aggregate instead of cement, AAM Concrete can reduce CO_2 emissions by more than 70%.

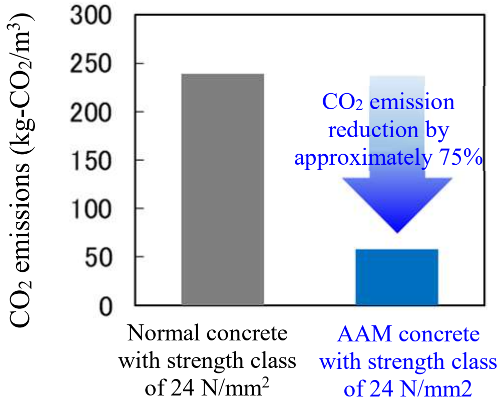


Figure 20.1 Example of comparison of CO_2 emissions during production

[2] Track record

AAM concrete is used for cast-in-place works, and prototypes are being produced for application to precast concrete products.

- Slope protection concrete
- Reinforcing building foundation (additional cast-in-place concrete)
- Concrete slab on grade
- Concrete block segment for revetment (mockup)

Photo 20.3 Slope protection concrete

Photo 20.4 Reinforcing building foundation (additional cast-in-place concrete)

Photo 20.5 Concrete slab on grade

Photo 20.6 Concrete block segment for revetment

(3) Future prospects

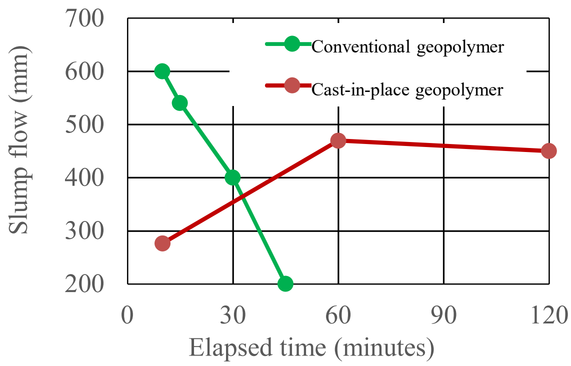
Currently, AAM Concrete is primarily being used for cast-in-place concrete in nonstructural members. We plan to conduct performance verification of AAM Concrete when applied to structural members. We also plan to commercialize precast products made with AAM Concrete at an early stage.

Cast-in-place Geopolymer (PolymerCrete®) by Obayashi Corporation [22]

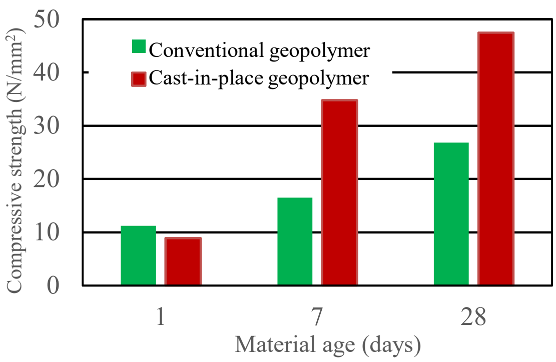
(1) Outline of the technology

Geopolymers are solid substances used in concrete as a replacement for cement, leveraging their ability to solidify when a silica-alumina powder, primarily composed of fly ash, a byproduct of thermal power plants, and ground granulated blast furnace slag, a byproduct of steel mills, is added to an alkaline solution. CO_2 emissions of geopolymers are 20 to 35% of those of ordinary concrete. Geopolymers are also characterized by high heat resistance, high durability under high temperature environments and other advantageous properties. In contrast, geopolymers have only been used for secondary products produced in factories because they have a very short pot life and require heat curing to achieve the necessary strength. Cast-in-place Geopolymer, PolymerCrete, can extend the pot life required for cast-in-place work and can be cast using a concrete pump truck through the addition of a special dispersant. Additionally, PolymerCrete can develop compressive strength through on-site ambient temperature curing. These unique properties enable PolymerCrete to have a broader range of applications than conventional geopolymer. PolymerCrete was used in a construction project in which the cross-section of a wall deteriorated by heat was restored by increasing the thickness by 10 cm. This experience confirmed the suitability of PolymerCrete for on-site work, demonstrating its workability and strength development under ambient temperatures.

Example of the application of PolymerCrete to cross-sectional restoration of RC retaining wall inside a steel mill



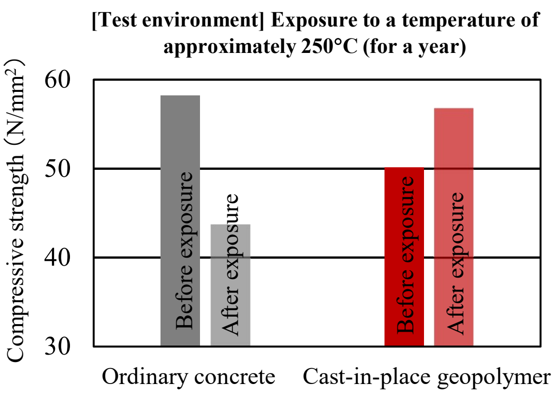
Slump flow



Compressive strength (ambient temperature curing)

Comparison between conventional geopolymer and cast-in-place geopolymer

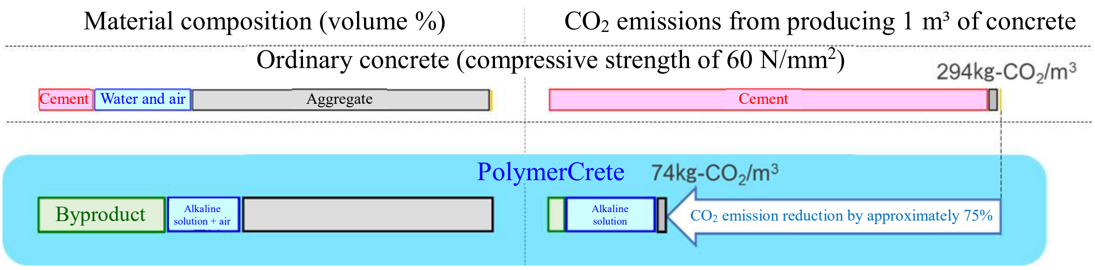
Similar to conventional geopolymers, PolymerCrete has superior heat resistance compared to ordinary concrete. In the exposure test (at an ambient temperature of 250°C for a year), it was confirmed that PolymerCrete demonstrated an increase in compressive strength of approximately 10%, while ordinary concrete showed a decrease of 25 to 30%. Previous tests have confirmed that, when ambient temperatures are around 250°C, PolymerCrete either shows no variation in compressive strength or demonstrates an increase.

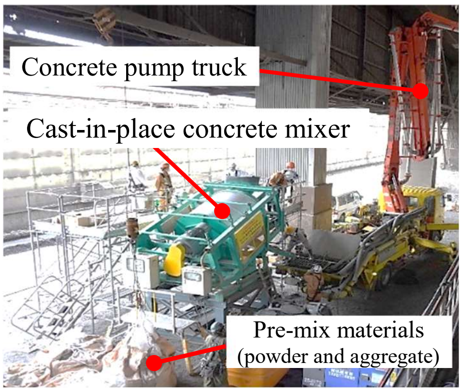


Comparison of compressive strength before and after high temperature environment exposure test

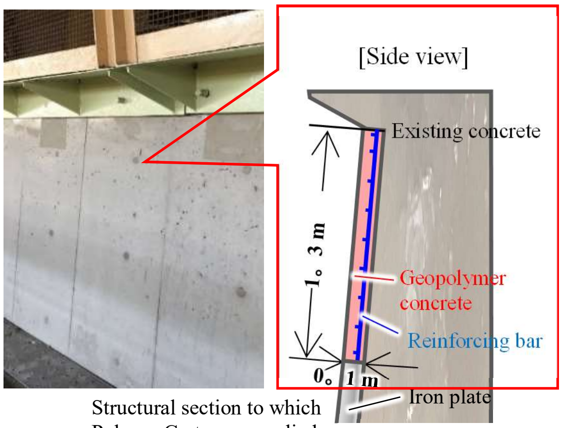
(2) Estimated or actual CO_2 reduction rates

Based on the mix of geopolymer used in the cross-sectional restoration of an RC retaining wall inside a steel mill, the CO_2 emission rate of the geopolymer is estimated to be approximately 74 kg/m^3. This rate is approximately 30% of that of ordinary concrete having equivalent strength, indicating a significant emission reduction of 70%. Additionally, by utilizing industrial byproducts such as fly ash and blast furnace slag as raw materials for the geopolymer, PolymerCrete can contribute to environmental preservation.





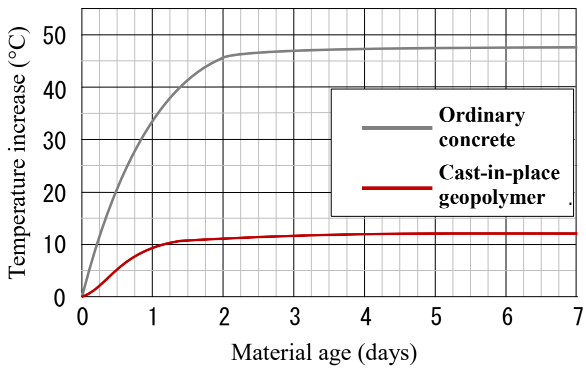
Casting PolymerCrete for cross-sectional restoration of RC retaining wall in a steel mill



Structural section to which PolymerCrete was applied

(3) Future prospects

We have conducted several types of tests to expand the application range of PolymerCrete. In an adiabatic temperature rise test, PolymerCrete demonstrated potential as a countermeasure for preventing thermal cracking in mass concrete. This is because it generates significantly less heat during solidification compared to cement concrete. Additionally, during a pumping test, it was confirmed that PolymerCrete maintained favorable fresh properties even after being pumped over a long distance equivalent to approximately 250 meters horizontally, with no impact on the development of compressive strength. PolymerCrete is expected to be used not only in low-carbon materials and high-heat-resistant materials but also in mass concrete that will be cast after undergoing long-distance pumping in the future.



Result of adiabatic temperature rise test

Situation of PolymerCrete discharged through a pipe after pumping

Sustain-Crete® by Sumitomo Mitsui Construction Co., Ltd. [23]

(1) Outline of the technology

Sustain-Crete is an environmentally friendly concrete that can reduce CO_2 emissions from materials by 40% to 90%. By optimizing the concrete mix and taking advantage of the material properties of industrial byproducts such as ground granulated blast furnace slag, fly ash, and silica fume, Sustain-Crete reduces the use of portland cement (hereinafter referred to as “cement”), which generates significant CO_2 emissions, to the extent possible while still enabling various structures to satisfy their required performance.
Sustain-Crete is characterized by the following three abilities.

[1] Ability to significantly reduce CO_2 emissions

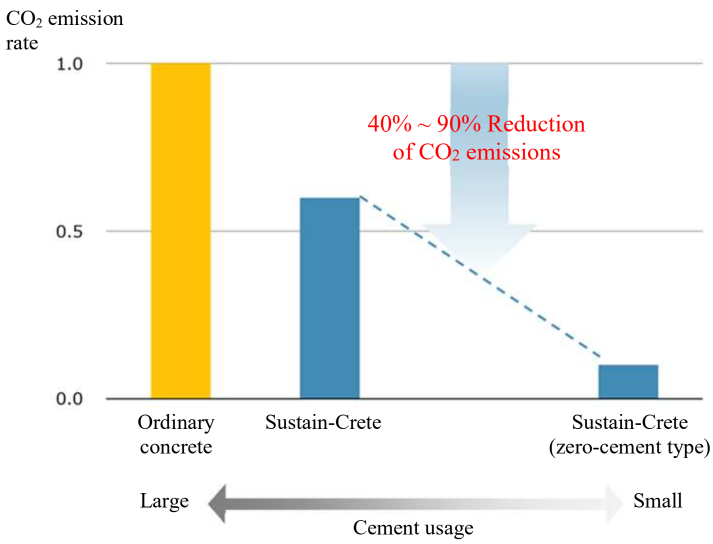
Given that Sustain-Crete uses a low volume of cement compared to normal Portland Cement, it can reduce CO2 emissions by more than 40%. In the case of a concrete mix that does not use any cement at all (zero-cement type), it can reduce CO_2 emissions by up to approximately 90%.

[2] Ability to achieve normal to ultra-high strength corresponding to a design strength of 220 N/mm^2

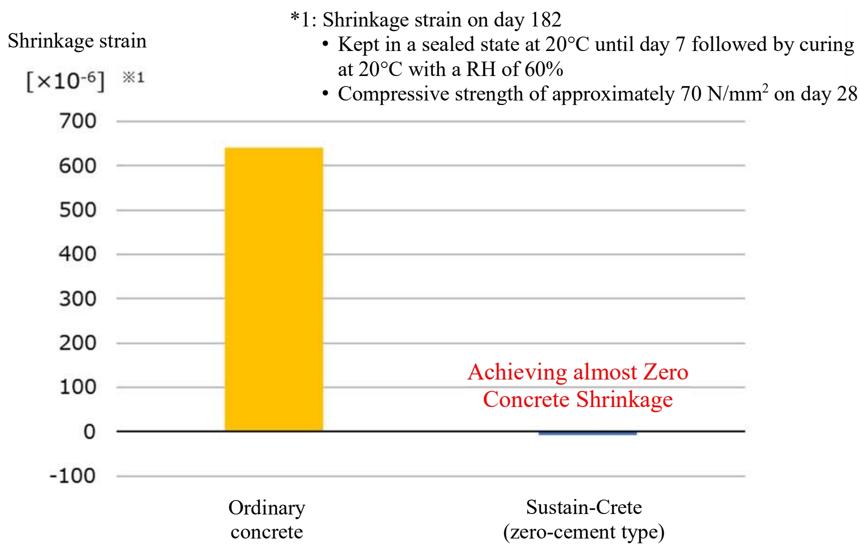
Sustain-Crete has a wider strength range than general environmentally friendly concrete. Typically, concrete members with ultra-high strength require a larger amount of cement than those with normal strength. In contrast, Sustain-Crete can reduce cement usage even for ultra-high-strength concrete members, thereby reducing CO_2 emissions.

[3] Ability to meet special concrete mix requirements for additional ultra-low shrinkage properties

Using a special concrete mix with a unique fine aggregate (ferronickel slag), which is an industrial byproduct, Sustain-Crete can achieve ultra-low shrinkage properties. This ability can significantly reduce the risk of cracks due to concrete shrinkage and thereby enhance the durability of structures.
Therefore, Sustain-Crete can be applied to structural members or sections where it is necessary to avoid shrinkage cracks, as well as to structural members or modeled objects with complex designs that make molding difficult due to shrinkage cracks when ordinary concrete is used.



CO_2 emissions from Sustain-Crete



Shrinkage properties of ultra-low shrinkage type Sustain-Crete

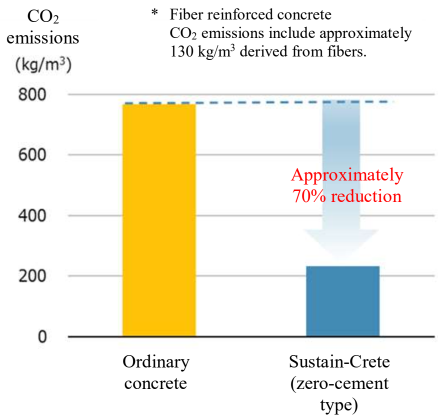
(2) Estimated or actual CO_2 reduction rates

[Application example]

Ultra-low shrinkage Sustain-Crete, which used no cement and was reinforced with short fibers, was applied to an environmentally friendly, highly durable PC bridge in combination with corrosion-resistant aramid FRP rods.

- Achieved a 70% reduction in CO_2 emissions with ultra-low shrinkage Sustain-Crete reinforced with short fibers, providing high strength of 140 N/mm²
- Achieved almost zero concrete shrinkage with enhanced ultra-low shrinkage properties

Erecting prestressed concrete girder



CO_2 emissions

(3) Future prospects

We will continue developing Sustain-Crete and promote its application in infrastructure renewal projects, specifically for replacing concrete slabs on deteriorated highway bridges to realize a decarbonized society.

Clean-Crete by Obayashi Corporation [25]

(1) Outline of the technology

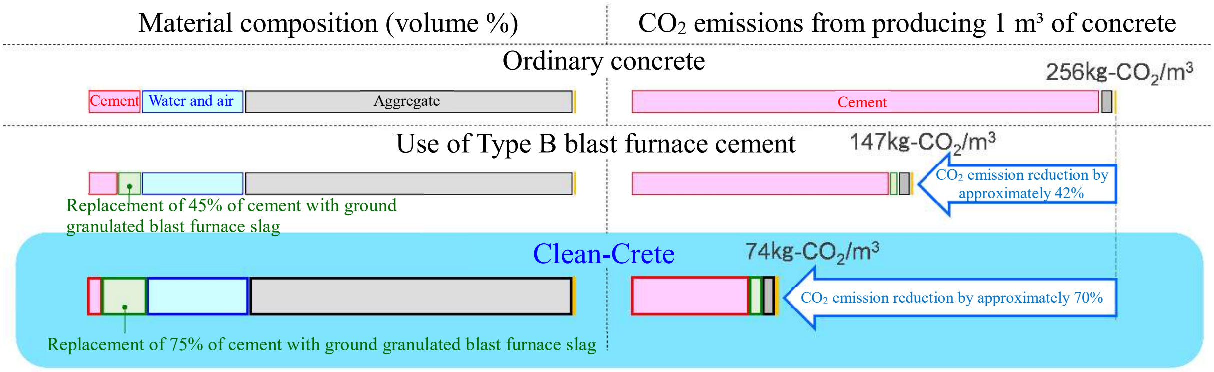
Concrete slabs for the railway track switching area at Tokyo Skytree Station

Temporary precast protection fence on the Yatomi viaduct of the Higashi-Meihan Expressway

Clean-Crete is a type of low-carbon concrete capable of reducing CO_2 emissions by up to 80% by replacing 60 to 90% of the cement with industrial byproducts (admixtures) such as ground granulated blast furnace slag, fly ash, and silica fume. Clean-Crete is characterized by workability and strength equivalent to that of ordinary concrete, as well as low heat generation properties and high resistance to salt damage. The standard mix of Clean-Crete is based on using ground granulated blast furnace slag for 65 to 75% of the mix, with portland cement making up the remaining 25 to 35%. Clean-Crete has no specific requirements for the production areas and compositions of ground granulated blast furnace slag, as long as the slag conforms to JIS standards. Additionally, Clean-Crete can minimize the strain on batching plants as it requires just ground granulated blast furnace slag that meets JIS standards, special admixtures, and specialized storage equipment like silos and dispensers for these materials. The versatility of Clean-Crete, due to its advantageous properties, has led to its use in more than 370,000 m³ across nearly 100 civil engineering and building construction projects, resulting in a total CO_2 emission reduction of about 65,000 tons, the largest in the construction sector, as of January 2023, since its development and commercialization in 2010. Clean-Crete has obtained a building material technical performance certificate from the General Building Research Corporation of Japan as an official certificate and is registered in both NETIS (KT-130003-VE) and the J-Credit Scheme. Additionally, the properties of Clean-Crete were evaluated in the Cooperative Research Reports Nos. 471 to 476 of the Public Works Research Institute.

(2) Estimated or actual CO_2 reduction rates

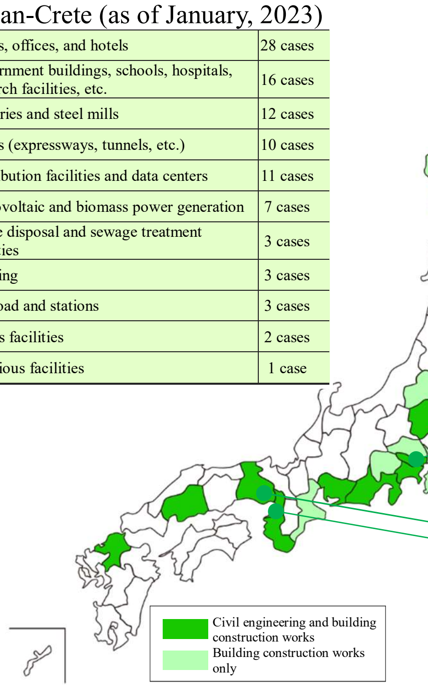
Clean-Crete with the standard mix can reduce CO_2 emissions by approximately 70% by replacing 75% of portland cement, which has CO_2 emissions of 760 to 770 kg-CO_2/ton, with ground granulated blast furnace slag, which has CO_2 emissions of 24 to 36 kg-CO_2/ton.



As of January 2023, Clean-Crete has achieved a track record of more than 370,000 m³ across nearly 100 civil engineering and building construction projects, resulting in a total CO_2 emission reduction of about 65,000 tons, the largest in the construction sector.

Outline of the track record of Clean-Crete (as of January, 2023)

Stores, offices, and hotels	28 cases
Government buildings, schools, hospitals, research facilities, etc.	16 cases
Factories and steel mills	12 cases
Roads (expressways, tunnels, etc.)	10 cases
Distribution facilities and data centers	11 cases
Photovoltaic and biomass power generation	7 cases
Waste disposal and sewage treatment facilities	3 cases
Housing	3 cases
Railroad and stations	3 cases
Sports facilities	2 cases
Religious facilities	1 case



ES CON FIELD HOKKAIDO

Oi District Tunnel on Shinagawa Line of the Central Circular Route

Kobe JCT

Mega solar power plant "Hikarinomori" on Yumeshima Island, Osaka

Track record of Clean-Crete

(3) Future prospects

• Expansion of applications

Currently, Clean-Crete has been used mostly in building construction works due to the ease of incorporating low-carbon concrete into their design. Thus, the applications of Clean-Crete are expected to be further expanded to civil engineering works in the future. To that end, critical challenges include applying Clean-Crete to cast-in-place reinforced concrete and precast concrete. Additionally, countermeasures against neutralization are needed when expanding its applications to aboveground reinforced concrete. For example, in building construction projects, Clean-Crete has already been used to fill in embedded precast formwork and used as fair-faced concrete for wall members coated with durable clear paint providing Clean-Crete with resistance to neutralization. Therefore, Clean-Crete is likely to have similar applications in civil engineering projects.

Use of Clean-Crete for the inside of the embedded formwork for erecting the girders that support the large roof **of ES CON FIELD HOKKAIDO**

Combination of Clean-Crete and clear paint for the external wall of a facility in the Technical Research Institute of Obayashi Corporation

• Appropriate cost

It is preferable for low-carbon concrete as a whole to have widespread applications through the standardization of slag for use in low-carbon concrete by various companies and appropriate pricing, following the unification of the methods for evaluating CO_2 emission reduction effects.

Slagrete® by Toda Corporation [27]

(1) Outline of the technology

Slagrete® is a type of low-carbon concrete that replaces 70 to 90% of the cement, by mass, with ground granulated blast furnace slag, a byproduct from steel mills. Using Slagrete® can significantly reduce the usage of cement which is the major source of carbon dioxide emissions during the production of concrete. Compared to ordinary concrete, Slagrete® can reduce CO_2 emissions by approximately 65 to 85%.

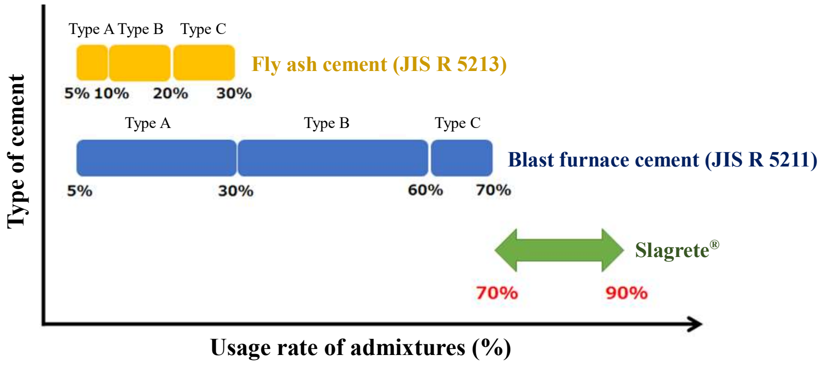


Figure 26.1 Usage rate of admixtures in Slagrete®

The characteristics of Slagrete® are as follows.

[1] By replacing 70 to 90% of cement with ground granulated blast furnace slag, Slagrete® can reduce CO_2 emissions by 65 to 85%.

[2] Slagrete® is expected to have a thermal cracking suppression effect compared to concrete made with ordinary portland cement or Type B blast furnace cement (see Figure 26.2).

[3] Slagrete® does not show significant differences in fresh properties, such as fluidity and pumpability, compared to general ready-mixed concrete. Therefore, Slagrete® can be cast in the same way as ordinary concrete.

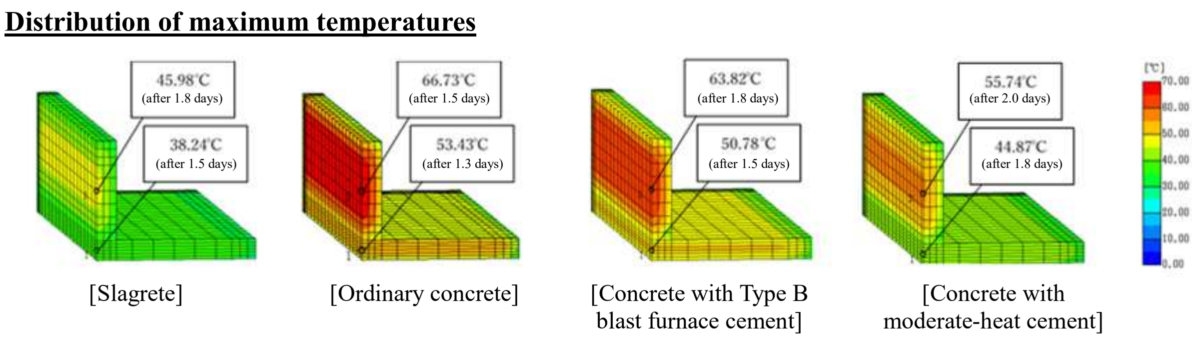


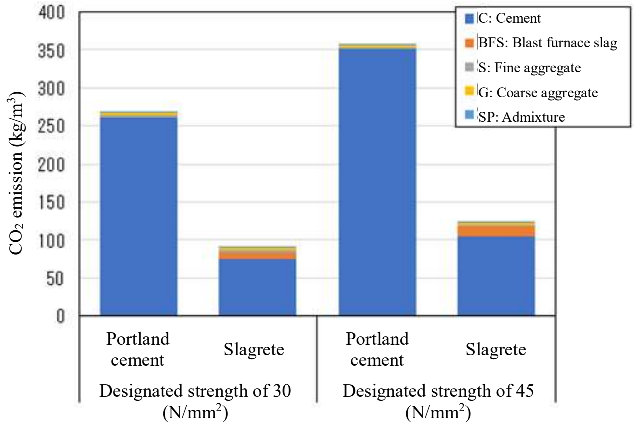
Figure 26.2 Thermal analysis result of a wall-like member

(2) Estimated CO_2 reduction rates

The CO_2 emissions from producing 1 ton of ordinary portland cement are approximately 760 kg, accounting for most of the CO_2 emissions from concrete.

By replacing 70% of the cement by mass with ground granulated blast furnace slag, Slagrete® can reduce CO_2 emissions by approximately 65% compared to concrete made with ordinary portland cement while achieving identical strength (see Figure 26.3).

*1: The CO_2 emission intensities of aggregate and admixtures are based on the Guidelines for Verifying Environmental Performance of Concrete Structures (Tentative Plan) published by the Japan Society of Civil Engineers in 2005.



* (When 70% of cement by mass is replaced with ground granulated blast furnace slag)

Figure 26.3 CO_2 emission reduction effect during the production of concrete

*In the case of a CO_2 emission intensity of 40.4 kg/ton by using ground granulated blast furnace slag with a fineness grade of 4000.

(3) Track record

- Retaining wall in land formation work
- Green Office Building in the Technology Research Institute of Toda Corporation (see Photo 26.1)
- Common ditch on the premises of the Technology Research Institute of Toda Corporation (see Photo 26.2)
- Slabs used in the Toda Building of Toda Corporation (see Photo 26.3)

Photo 26.1 Green Office Building

Photo 26.2 Common ditch

Photo 26.3 Slab

(4) Technical registration and certification acquisition

- NETIS: Registration No. QS-210008-A
- Building Material Technical Performance Certificate: GBRC Material Performance Certificate No. 20-01
- EcoLeaf Registration No.: JR-BY-23001E (Slagrete® 70 (Nominal strength of 40 or less))

(5) Future prospects

As part of our efforts to realize a decarbonized society, we will proactively promote and expand the application of Slagrete® to actual structures in the civil engineering and architectural sectors. Additionally, in the civil engineering sector, we plan to apply Slagrete® to secondary concrete products to expand its applications.