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New ecological concrete that reduces CO_2 emissions below zero level

~ New method for CO_2 capture and storage ~

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Abstract

We have developed a new ecological concrete which can achieve a CO_2 emission level below zero by capturing CO_2. This concrete is based on two typical features. One of the features of this concrete is using a special admixture (the *γ* phase of dicalcium silicate: γ-2CaO.SiO_2) instead of cement. This material has a very low level of CO_2 emissions and hardens the concrete by reacting with CO_2. The other feature of this concrete is capturing the CO_2 contained in the exhaust gas from thermal power stations. In this paper, we set forth the concepts of the development and various results of examination of the ecological concrete. This ecological concrete is named "CO_2-SUICOM" (CO_2 Storage under Infrastructure by Concrete Materials).

Keywords: CO_2 Emision; CO_2 Storage; Carbonation curing chamber; Exhaust gas; Concrete; Thermal power station; γ-C_2S

1. Introduction

The reduction of greenhouse gases has become a priority issue in various industries.

On the one hand, the electric power industry accounts for approximately 30% of the CO_2 emissions generated in Japan. Therefore, enhancement of thermal efficiency in power stations and expansion of renewable energy such as hydro power, solar power and wind power are being promoted.

On the other hand, efforts are being made to reduce CO_2 emissions also in the concrete industry in Japan. A large amount of CO_2 is emitted during the manufacturing process of cement. For this reason, using by-products such as fly ash or granulated blast-furnace slag - which have low CO_2 emissions -

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instead of cement is the main method to reduce CO_2 emissions in the concrete industry. For instance, according to the Japan Society of Civil Engineers (JSCE), the CO_2 emissions can be reduced about 15% by using fly-ash type B, and reduced about 40% by using blast-furnace slag type B.

Under the circumstances mentioned above, The Chugoku Electric Power Co., Inc., Kajima Corporation, and Denki Kagaku Kogyo Kabushiki Kaisha have jointly developed a new ecological concrete which can achieve a CO_2 emission level below zero by capturing CO_2 emitted from thermal power stations. This is the first technology of its kind in the world.

This ecological concrete is named "CO_2-SUICOM" (CO_2 Storage under Infrastructure by Concrete Materials).

2. Concepts of the development

Fig.1 shows conceptual schematics of the emission of CO_2 with ordinary concrete and reduction of CO_2 with the new ecological concrete. This concrete is based on two typical features. One is using a special admixture (the γphase of dicalcium silicate : γ-$2CaO.SiO_2$ ("γ-C_2S" below)) instead of cement. This material has a very low level of CO_2 emissions and hardens the concrete by reacting with CO_2. The quantity of CO_2 emitted with this material is about one-fifth of that of ordinary portland cement. Since γ-C_2S does not react with water, it does not contribute to ordinary concrete. However, when it reacts with CO_2, it has strength development greater than ordinary portland cement. Moreover, this concrete uses coal-ash instead of cement, and so this concrete not only can reduce the quantity of CO_2 emitted from thermal power stations, but also can use by-products like coal-ash effectively.

The other feature of this concrete is capturing CO_2 contained in the exhaust gas from thermal power stations. After this concrete is manufactured, it is set in a chamber. Exhaust gas is drawn into the chamber, and the CO_2 contained in the exhaust gas is captured in the concrete.

The CO_2 emissions of this concrete can be reduced by half compared to ordinary concrete by using γ-C_2S and coal-ash. Moreover, more CO_2 than is emitted by the concrete is captured in the hardening process of the concrete. Overall therefore, the CO_2 emissions of the newly developed concrete can be below zero.

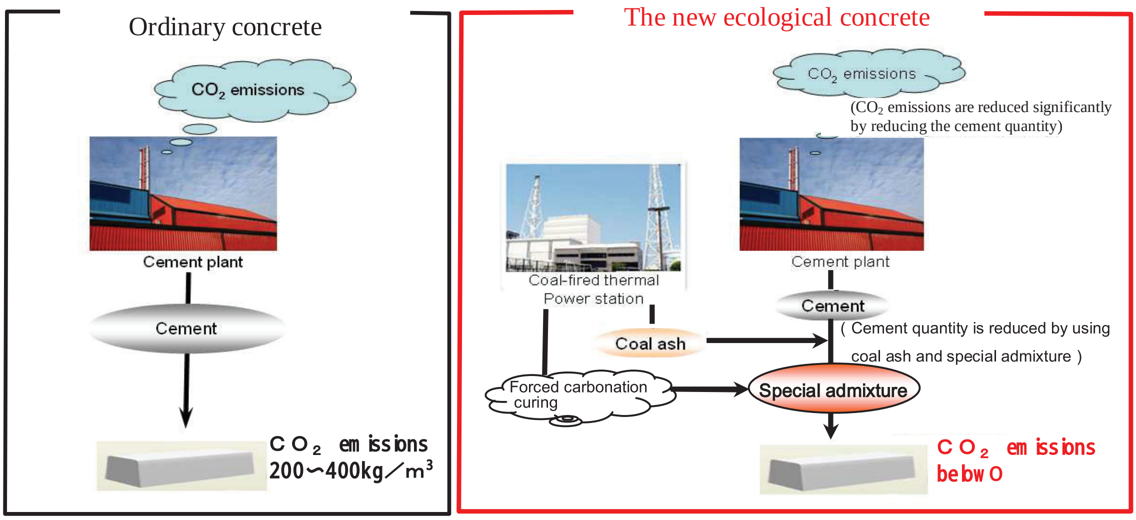


Fig. 1. Concepts of the development

3. Details of the development

Kajima Corporation and Denki Kagaku Kogyo Kabushiki Kaisha commenced research on forced carbonation (absorption of CO_2) curing for obtaining densefied concrete, and developed the technology to enhance its durability, in 2006. However, ensuring a stable and constant CO_2 supply source became an issue.

At this stage, The Chugoku Electric Power Co., Inc., Kajima Corporation and Denki Kagaku Kogyo Kabushiki Kaisha turned their attention to the exhaust gas of thermal power stations, and began studies on the use of such exhaust gas as a CO_2 supply source. We also studied the effective utilization of coal-ash from thermal power stations, beginning in August 2008.

During the development stage, technical issues in the use of exhaust gas from thermal power stations as a CO_2 supply source were overcome in the laboratory. Subsequently, from November 2009, carbonation curing equipment was installed on site at the MISUMI Power Station (a coal-fired thermal power station) of The Chugoku Electric Power Co., Inc. The exhaust gas generated in the power station was drawn into the carbonation curing equipment, the CO_2 was absorbed in the concrete, and confirmatory tests relating to carbonation and concrete strength were carried out. The carbonation curing chamber and its inside are shown in Fig. 2 (a) and (b).

From the studies on the concrete mix proportion and improvements in the manufacturing method, this ecological concrete was confirmed to have the same quality as conventional concrete.

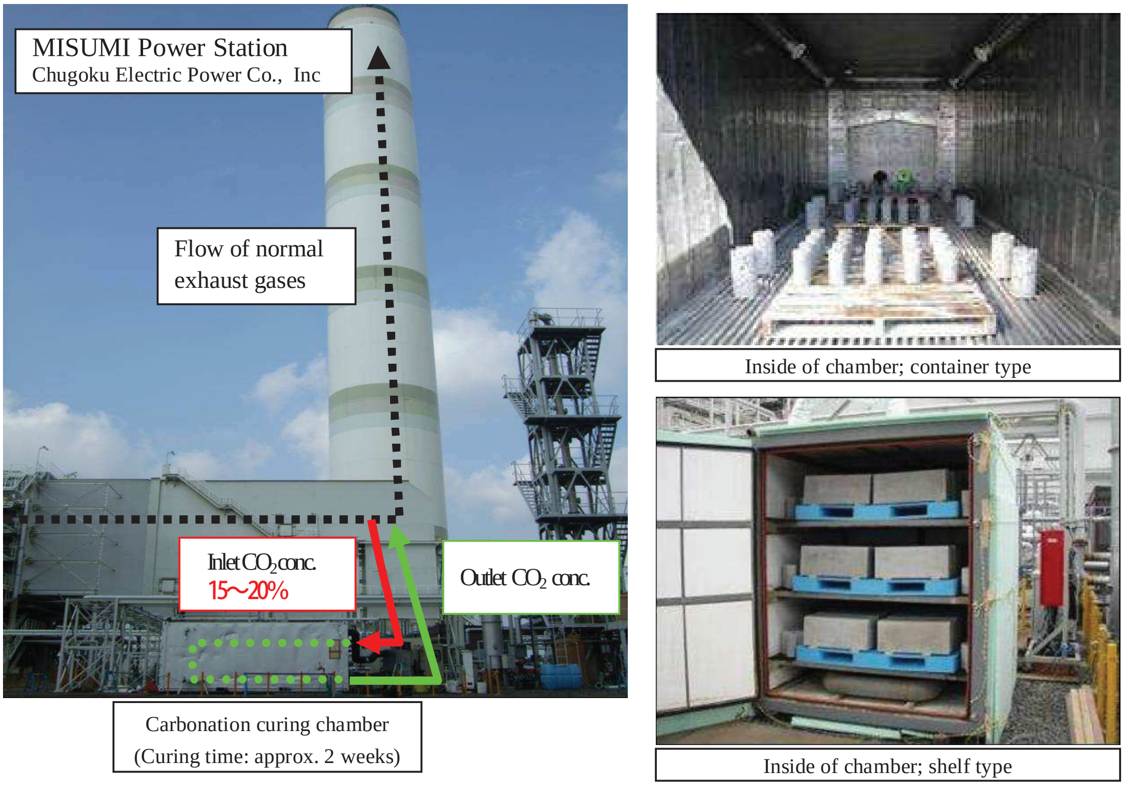


Fig.2. (a) Carbonation curing chamber at MISUMI Power Station; (b) Inside of carbonation curing chamber

4. Outline and features of the new ecological concrete

4.1. Manufacturing approach

The new ecological concrete makes use of a special admixture (that reacts with CO_2) and coal-ash, besides the ordinary concrete materials (water, cement, aggregate). By curing concrete containing these materials for two weeks under CO_2exposure, the concrete hardens through the carbonation reaction of the special admixture, in addition to the hydration reaction of the water and cement.

Table 1 shows a comparison of the typical features for ordinary concrete and for the new ecological concrete CO_2-SUICOM.

Table 1. Differences between ordinary concrete and the new ecological concrete CO_2-SUICOM

	Ordinary concrete	The new ecological concrete CO_2-SUICOM
Concrete materials	Water + cement + aggregate	Water + cement + aggregate + special admixture + coal-ash
Curing method	Water curing or air curing	Curing by CO_2 contained in gas emitted from thermal power station
Hardening reaction	Hydration reaction between water and cement	Carbonation reaction of CO_2 and special admixture in addition to hydration reaction between water and cement

4.2. Special admixture

The special admixture consists mainly of γ phase dicalcium silicate (γ-C_2S) (Fig. 3). There are several manufacturing methods, but the quantity of CO_2 generated during manufacture of the special admixture can be reduced by using a byproduct instead of limestone. If so, the quantity of CO_2 emitted will be about one-fifth that of ordinary cement.

Fig. 4 shows the CO_2 emissions from manufacture of ordinary portland cement and γ-C_2S using limestone and using a by-product.

The chemical reaction of carbonation with γ-C_2S is given by Equation (1):

$$\gamma\text{-}2CaO.SiO_2 + 2CO_2 \rightarrow 2CaCO_3 + SiO_2\,(\text{gel-like}) \qquad (1)$$

Since γ-C_2S does not react with water, it does not exhibit strength development when used in ordinary concrete. However, when it reacts with CO_2, it has strength development equivalent to or greater than that of cement .

A phenomenon called “neutralization” occurs during reaction with CO_2 in the air in ordinary concrete, but the neutralization depth after 20-30 years may be only about 10 mm from the surface. In contrast, when a large quantity of CO_2 is absorbed in the new ecological concrete by controlling the curing temperature and humidity, the concrete’s CO_2 emissions can be significantly reduced, even if the CO_2

emitted during manufacture of the concrete is not considered. Fig. 5. (a) shows a BSE (Back Scattered Electron) image of γ-C_2S particles before carbonation curing. The black part is space and the light gray part is γ-C_2S. Fig. 5. (b) shows a BSE image of γ-C_2S particles after carbonation curing. The space (black part) is filled by $CaCO_3$ and an SiO_2 gel-like substance, which form a dense matrix .

Fig. 3. Appearance of γ-C_2S

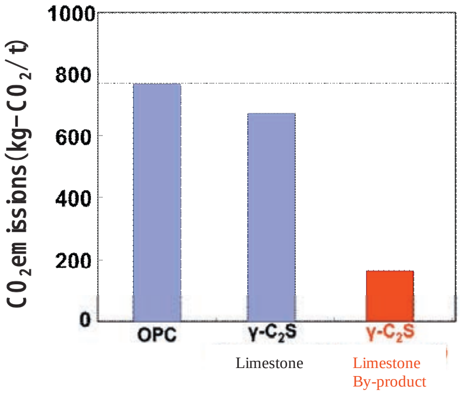


Fig. 4. CO_2 emissions from manufacture of cement andγ-C_2S

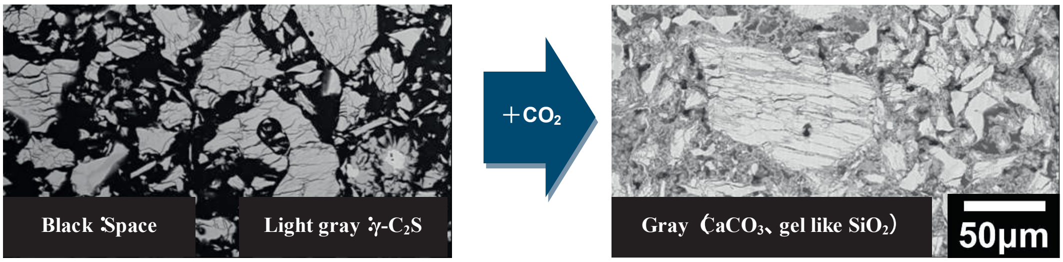


Fig. 5. (a) BSE image of noncarbonated γ-C_2S (b) BSE image of carbonated γ-C_2S

4.3. CO_2 absorption method

Exhaust gas from fuel combustion is drawn into the curing chamber and the CO_2 contained in the exhaust gas is absorbed in the concrete. The exhaust gas returns to the original system from the curing chamber and is discharged through a chimney (Fig. 2).

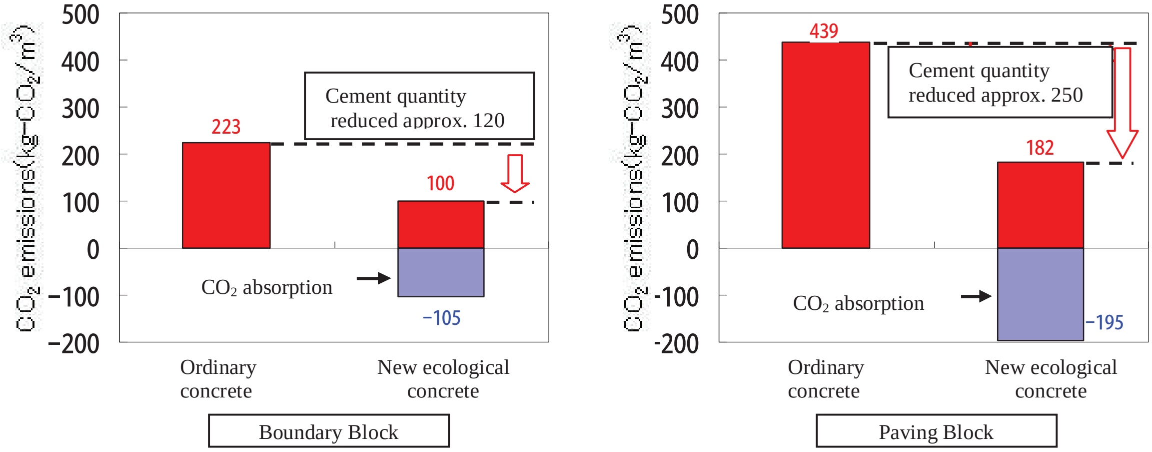
In our experiment, the CO_2 concentration in the exhaust gas at the inlet of the chamber was approximately 15% to 20% (the CO_2 concentration in air is approximately 0.04%), but the concentration will also depend on the operating condition of the power station.

To use the CO_2 in the exhaust gas from thermal power stations, about two weeks of curing is required. How to reduce this period is an issue that will be studied in the future.

Experiments were conducted to study the effects of the NO_x and SO_x contained in minute amounts in the exhaust gas on the performance of the concrete, and the results confirmed that almost no difference in strength and porosity occurs. However, it was also found that the NOx and SOx hindered the speed of CO_2 absorption. Accordingly, a system to remove these gases in the process of supplying the exhaust gas has been developed.

4.4. Reduction of CO_2 emissions

As shown in Fig. 5, the CO_2 emissions during manufacture of this concrete can be reduced to approximately 120 to 250 kg/m^3 compared to ordinary concrete by using a special admixture and coal-ash. Moreover, approximately 100 to 200 kg/m^3 of CO_2 is absorbed in the hardening process. The experimental results show that the CO_2 emissions from the stage of manufacturing the cement - which is a component of the concrete - to the stage of curing and manufacturing the concrete can be reduced to substantially below zero. [Note]



(* Does not include CO_2 emissions resulting from temperature and humidity control of curing chamber)

Fig. 6. (a) CO_2 emissions of Boundary Block (b) CO_2 emissions of Paving Block

4.5. Quality

Although the quantity of cement used for this concrete is significantly lower than for ordinary concrete, the basic quality of this concrete is equivalent to that of the conventional product, as shown, for instance, by the strength properties in Table 2. Since the newly developed concrete is low in alkalinity compared with the ordinary concrete, it will have low impacts on ecosystems. Other features include the ability to resist efflorescence and abrasion.

Table 2. Performance of the new ecological concrete product

	Image	Fukuyama Solar Quantity used	Required performance	Performance verification status
Boundary block		75 units	Comp. strength 18N/mm^2	Required performance is satisfied
Fence foundation block		40 units	Comp. strength 18N/mm^2	Required performance is satisfied
Paving block		About 5,500 units	Flex. strength 5N/mm^2 （for roadway）	Required performance is satisfied

5. Applications of the new ecological concrete

This newly developed product has already been used in construction work.

In February 2011, concrete products using this new technology were used at the information facilities of the Fukuyama Photovoltaic Power Station of The Chugoku Electric Power Co., Inc. (Fig 7). In this work, CO_2-SUICOM was used for boundary blocks (Fig. 8), foundation blocks (Fig. 9), and paving blocks (Fig. 10). This field trial demonstrated that the required performance of CO_2-SUICOM is satisfied.

In January 2012, building elements using CO_2-SUICOM were used in the terrace ceiling of a condominium named NAKANO Central Park Residence (Fig. 11). This ceiling using CO_2-SUICOM is presented in Fig. 12.

By the application of CO_2-SUICOM, 100 to 200 kg/m^3 of CO_2 was absorbed in the hardening process of concrete.

Fig. 7. FUKUYAMA Photovoltaic Power Station

Fig. 8. Application to boundary blocks

Fig. 9. Application to foundation blocks

Fig. 10. Application to paving blocks

Fig. 11. NAKANO Central Park Residence

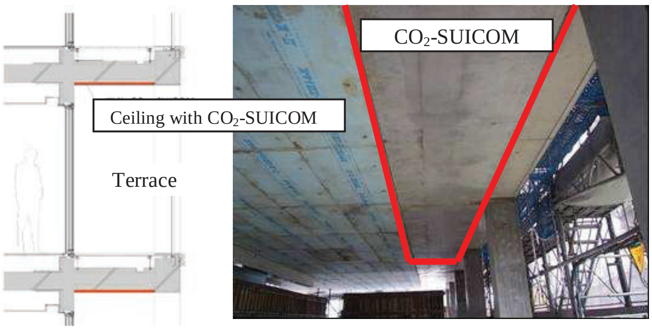


Fig. 12. Application to building elements

6. Conclusions

In this paper, we have set forth the development of a new ecological concrete named "CO_2-SUICOM" (CO_2 Storage under Infrastructure by Concrete Materials).

It is found that the CO_2 emissions of this concrete can be reduced by half compared to ordinary concrete by using γ-C_2S and fly-ash. Moreover, more CO_2 than is emitted by the concrete is captured in the hardening process of the concrete. Overall therefore, the CO_2 emissions of the newly developed concrete can be below zero. The more of this new ecological concrete that is produced, the more CO_2 will be absorbed. It has potential to play a CO_2-absorbing role like that of trees. This concrete can be expected to be applicable to various kinds of construction work.

In the near future, the concrete's long-term durability will be evaluated. Also, studies are scheduled that will aim for industrialization of the concrete, expansion of the range of products to which it is applicable, and large-scale products using the concrete.