Profile-4

Expectations for carbon-recycled concrete to realize a carbon-free society Development of concrete as "Beyond-Zero" materials

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Towards "beyond zero"

Japan has declared it will be carbon neutral by 2050 and has set a target of reducing greenhouse gas emissions by 46% by FY2030 compared to FY2013. The government sees this as an opportunity for growth through a "virtuous cycle between economy and environment" and has launched the Green Growth Strategy to achieve it. As part of this strategy, carbon recycling technology is being developed to utilize carbon dioxide (CO_2), a major greenhouse gas, as a resource.

The production of ordinary concrete results in the emission of 260 to 300 kg of CO_2 per m^3. Most of this CO_2 is released during production of the Portland cement used in the concrete mix. The author's group has been developing various types of environmentally friendly concrete that reduce usage of Portland cement by replacing it with a by-product from steelmaking (blast furnace slag fine powder), thereby suppressing CO_2 emissions (Fig. 1). Our zero-cement concrete, which uses no Portland cement at all, reduces CO_2 emissions by up to 80% and is expected to contribute to the FY2030 target; however, this is still not meet the need the carbon neutral criterion. Further, to meet the government's target, it is not enough to be carbon neutral; considering that other production activity in the economy will be associated with inevitable CO_2 emissions, it is desirable to do even better.

In light of progress in carbon recycling technology, we came up with the idea of combining a recycled carbon material (calcium carbonate), formed using CO_2 recovered from exhaust gases and other sources, with environmentally friendly concrete technology. In 2019, we began development of recycled carbon concrete with the aim of going "beyond zero" CO_2 emissions and fixing large amounts of CO_2.

Characteristics of recycled carbon concrete

The following issues have generally been faced in fixing CO_2 in concrete:

- ✓ Direct adsorption of acidic CO_2 gas by reinforced concrete leads to loss of its strong alkalinity, which has an anti-corrosion function in respect of the reinforcing steel. On the other hand, if CO_2 absorption is limited to the extent that it does not reach the reinforcing steel, the amount of CO_2 that can be fixed becomes small.
- ✓ If concrete porosity is increased to facilitate CO_2 absorption, the concrete will become porous and lose strength.

Our recycled carbon concrete solves these problems by first converting collected CO_2 into calcium carbonate to reduce its chemical impact on the concrete, and then mixing it into strongly alkaline concrete with blast furnace slag fine powder as the main binder component. By making use of knowledge obtained through the development of environmentally friendly concretes, we were able to achieve appropriate workability and strength characteristics even with a high proportion of calcium carbonate. The features of this recycled carbon concrete are as follows:

1) The amount of CO_2 fixed is 70 to 170 kg per m^3 of concrete.
2) The amount of CO_2 fixed exceeds the amount of CO_2 emitted in the manufacture of the materials used, including the calcium carbonate, resulting in a CO_2 emission balance of -55 to -5 kg/m^3. (Since the production of calcium carbonate by carbon recycling is still in the process of commercialization, this calculation assumes that 0.5 kg of CO_2 would be emitted in the capture and fixing of 1 kg of CO_2.
3) By avoiding the adsorption of CO_2 as a gas, the strong alkalinity of the concrete is maintained, preserving its anti-corrosion performance. Further, the fresh properties of the concrete (slump 12-21 cm or slump flow 45-60 cm) and its strength characteristics (compressive strength: 20-45 N/mm^2) are unchanged. This means that conventional design and construction techniques and experience are appropriate.
4) The new concrete can be manufactured using the normal facilities available at ready-mixed concrete plants. It can be used for on-site casting and for secondary products.
5) The CO_2 is converted in advance to calcium carbonate for delivery to ready-mixed concrete plants and construction sites, so there is no need to handle high concentrations of CO_2 gas and there are no safety concerns.

Expectations and Issues for Carbon Neutral

As explained above, the CO_2 emissions of recycled carbon concrete are negative. That is, offsetting carbon by use of this concrete will contribute to achieving carbon neutrality by 2050. The collection and recycling of carbon will also contribute to a virtuous cycle of resource use between the economy and the environment. Furthermore, with performance equivalent to that of normal concrete, we can expect a smooth transition to the new concrete as a basic material in a decarbonized society.

On the other hand, materials utilizing recycled carbon are new, so there are as yet no standards, legal systems, or track records for the use of concrete using such materials. The infrastructure we build must be safe and secure, but the foundations of a safe infrastructure are standards and legal systems, along with an accumulated track record. They are two sides of the same coin. We must find a way forward by developing standards and legal systems to allow.

Achieving carbon neutrality requires a large amount of recycled carbon materials to be available. Such quantities cannot be produced only using methods that are environmentally and economically efficient. The balance between the environmental and economic aspects of the circular economy on one side and the performance and quality of products (including concrete) on the other is important. Optimization must be achieved within the system we call the earth. For such optimization to take place, an urgent need is to establish environmental assessment methods and carbon pricing for carbon recycling.

Society is moving rapidly toward the year 2050. Today's recycled carbon concrete is one of our best available technologies (BATS), meaning one of the best techniques available at the moment, and we should strive to improve it day-by-day.