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A study on development of recycled cement made from waste cementitious powder

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HIGHLIGHTS

- It is possible to use cementitious powder from waste concrete as the main ingredient of recycled cement.
- Formation of cement major compounds (C_2S, C_3S, C_3A, C_4AF) was verified in recycled cement.
- Burnility is not sufficient at a temperature of less than 1400 °C.
- Long term compressive strength of recycled cement was up to 76.5% compared to OPC.

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ABSTRACT

With the goal of achieving sustainable development, many studies have been performed on approaches to reducing environmental load and cutting construction-related waste and greenhouse gas emissions. For this reason, this study aims to reduce carbon emissions and preserve the fixed materials such as limestone by utilizing the presumably high value-added cementitious powder of waste concrete, which is not currently being recycled.

First, the chemical properties of cementitious powder were analyzed to manufacture recycled carbonic cement by deriving the optimal mix proportion of the materials using the industrial byproduct (former slag) and limestone as a property adjustment. To make a clinkering evaluation, Free CaO measurement, an XRD analysis, a thermal analysis, a compressive strength test and a flowability analysis were performed. Through this series of analyses, overall properties were found to be at 80% those of OPC or better. In addition, when using the cementitious powder as a substitute for limestone, it was discovered that the carbon emissions were reduced by up to 46%. However, as the amount of fine aggregate that was not separated from the cementitious powder due to its similar grain size and shape increased, the plasticity and the reduction in carbon emissions were radically decreased. Moreover, when the fine aggregate was mixed in the proportion of more than 30%, it is believed to be hardly materialized. Therefore, an effective separation technology of cementitious powder from fine aggregate should be researched and developed in the future.

1. Introduction

As part of many efforts recently made to reduce the environmental load on the premise of the sustainable development, environmental regulations have been enhanced including international agreements. Under this societal background, many studies have been conducted to reduce construction-related waste and greenhouse gas emissions [1,2].

In terms of waste, the construction waste accounts for about half of the entire industrial waste, 65% of which is taken up by waste concrete. With the advancement of the cement industry, it shows a continuous increasing trend, and for this reason, research and development of the technologies for recycling waste concrete have been done at the national level, and recycling aggregate is at the commercial use as the result. In addition, some studies have been conducted to recycle the cementitious powder of paste ingredient with no fine aggregate and the fine powder with fine

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aggregate produced after the recycled aggregate is manufactured. Through these studies recycled fine powder is generally used as inert fillers in replacement of stone powder in the manufacture of cement products such as roadbed material or bricks, but no research has been conducted to apply this as the raw material of cement [3,11].

Most industrial waste is buried, but reclaimed land has decreased due to the NIMBY phenomenon. In addition, the toxic substances of heavy metals in the industrial waste generate leachate, leading to the contamination of underground water, which has caused a serious social problem, and for this reason R&D efforts have been made to recycle these substances. In particular, construction waste has a highly adverse impact on the ecosystem by contaminating underground water and soil due to the strong alkali property of toxic substances of heavy metals, including hexavalent chrome, a known carcinogen.

Therefore, to reduce waste and greenhouse emissions in the cement industry and develop recycled cement using waste powder as the main material, clinker was manufactured according to the mix design for multi-objective optimization, and then hydration recovery and physical properties were assessed. Moreover, instead of using limestone as the main material of cement, CaO was supplied through the dissolution of portlandite ($Ca(OH)_2$ (76 g/mol) → CaO (56 g/mol) + H_2O (20 g/mol)) not through decarboxylation ($CaCO_3$ (100 g/mol) → CaO (56 g/mol) + CO_2 (44 g/mol)), and it is expected that CO_2 would be reduced, which would be quantitatively assessed using a simple calculation, and compared with OPC to ultimately estimate the reduced amount of CO_2.

2. Theoretical review

2.1. Actual state of recycling of construction waste

Each and every nation has strived to curve the construction waste in the center of government. For instance, in Japan by establishing the recycling law in 1991, the recycling target was set by type of construction waste as was in Korea, and the designated companies with a certain level of scale have been obliged to recycle construction waste, but most of the recycled construction waste is recycled aggregate and paste ingredient would be buried or used as stone powder in manufacturing cement-type products. In addition, in German constructor and public offices are responsible for systemic connection of dismantlement and construction work to set the objective of reducing construction waste and put an emphasis on the achievement of the objective. In Denmark, waste concrete was used in road pavement in 1929, in airport pavement in 1959, and in road pavement for vehicles, and with the increase in the volume of construction waste, diverse studies have been done on the recycling of the waste concrete. As aforementioned, the physical properties of the waste concrete is not greatly deviated from the original properties even after it is recycled, and it can be utilized in many ways and has a high added value, but the recycling technology for it needs to be improved to recycle it as a high value-added material [17].

2.2. Technology and efforts to reduce carbon emissions in the cement industry

With the global warming getting more serious, many international agreements are entered into between nations in order to reduce greenhouse gas emissions. In particular, it was found that CO_2 accounts for 89% of the greenhouse gas, which have a high impact on the global warming, and it is often mentioned as the target index of greenhouse gas for reduction. Fig. 1 below shows the carbon emissions by nation, from which it is found that CO_2 continues to increase even after the 1997 Kyoto Protocol, and it appears that the carbon emissions from the top 9 heavy carbon emitting countries reached over 190 tons in 2010. It is believed that much energy is needed due to the industrial advancement. It is analyzed that in the construction sector, the greenhouse gas emitting from indirect production and transport of construction materials related with the actual construction takes up 11.3%, which implies that to reduce CO_2 from the production and transport of construction materials would be effective to cut the entire carbon emissions. In particular, a half of the entire emissions or 5% is from the cement industry, about 83% of which is from the sintering process. The proportion of carbon emissions in the cement industry is indicated in Table 1 [2,4–11,15].

In Japan, to reduce the basic unit of energy for the cement manufacture, preliminary jaw crushers have been installed, and high-performance separators were introduced, high-efficient facilities have been penetrated, and the use of energy substitute has been expanded, and the use of premixed cement has been expanded at the national level; the government of the U.K. presented a vision to reduce carbon emissions by 60% for 60 years through the same method as Japan does by setting short-term (1990–2010), mid-term (2010–2030) and long-term (2030–2050) plans. In addition, American Concrete Institute established a voluntary long-term objective in 45 companies and 101 factories to reduce 10% of carbon emissions by 2020 compared with those in

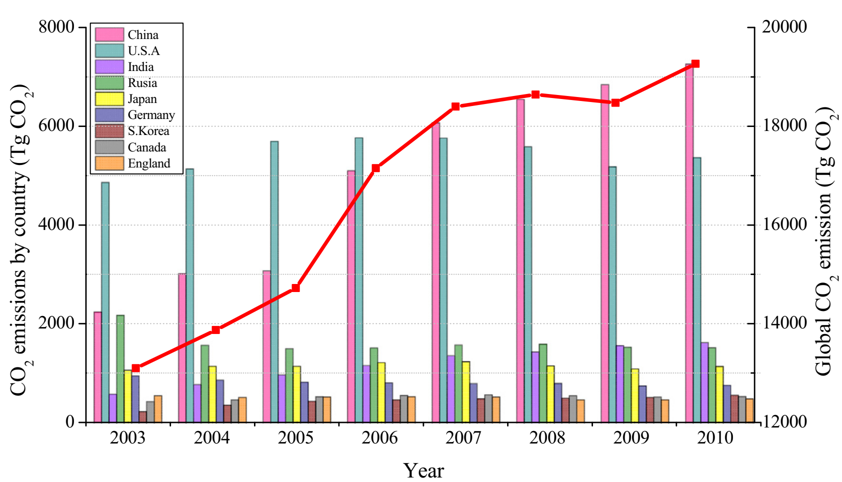

Fig. 1. CO_2 emissions by countries.