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Development of Advanced Recycling Technology for Fly Ash to Enable Cement-free Concrete

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Approximately 5.4% of all CO_2 emissions in Japan come from concrete, and over 90% of CO_2 emissions from concrete are derived from cement. Compared with cement, geopolymers emit approximately 80% less CO_2 and have a much smaller environmental footprint. However, geopolymers require the use of an active filler such as fly ash or ground granulated blast-furnace slag. Because of the potential detrimental effects on concrete fluidity, the unburnt carbon content in fly ash must be 3% or lower when it is used an active filler. The principal investigator has investigated and developed a novel flotation technique and equipment for improving fly ash quality by effectively removing unburnt carbon. This technique has been successfully used to improve fly ash quality under test conditions.

The objective of this R&D project was to further develop the system for generating high-grade material from low-grade fly ash so that the system reaches a level where it can be practically implemented and used to develop a geopolymer concrete with the ultimate goal of reducing CO_2 emissions from concrete by 80%.

The results of the R&D project suggest that modified fly ash slurry (MFAS) can be refined into high-grade fly ash using a hydrocyclone. Furthermore, in addition to establishing a method for reducing the moisture content of MFAS from around 90% to around 25% where the MFAS can be used in geopolymer concrete, we demonstrated that the improvement process also partially removes heavy metals from the fly ash. Based on those results, we developed a quality-improvement/recycling system for low-grade fly ash using laboratory equipment (Fig. 1).

After discussing the potential for developing a geopolymer concrete that has a moderate curing temperature and uses MFAS, we compiled basic manufacturing facility-related data and proposed a system flow for a plant to manufacture geopolymer concrete using MFAS cake.

We demonstrated that CO_2 emissions from concrete can be reduced by 50% by utilizing the novel technique that we developed to improve the quality of low-grade fly ash and then using this modified fly ash as an active filler in geopolymer concrete. The technique developed through this R&D project will enable CO_2 emissions from concrete to be reduced, thereby contributing to environmental policies aimed at achieving the emissions reductions targets set out in the Paris Agreement.

The flotation technique relies on only the motive power of a circulation pump and a flotation agent without the need for a firing process that uses fuel. Although this technique is associated with an extremely low environmental load and is relatively inexpensive, the resulting modified fly ash is in the form of slurry mixed with water. One scientifically significant accomplishment of this R&D project was demonstrating that MFAS can be refined into high-grade fly ash by using a hydrocyclone. Another

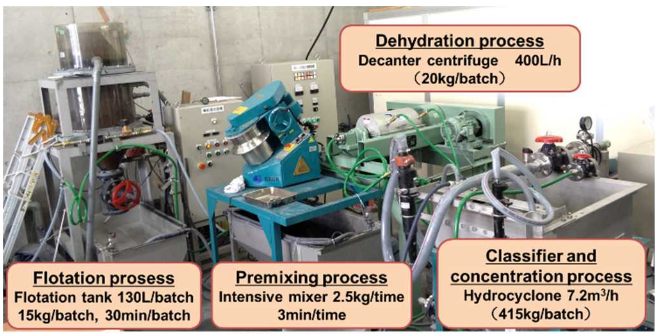

Fig. 1 Laboratory scale MFAS manufacturing equip-ment (15 kg/batch, 28.8 ton/y).

significant accomplishment was the development of a technique to reduce the moisture content of MFAS from around 90% to around 25%, which will allow MFAS to be used in geopolymer concrete. MFAS's high moisture content is also problematic if it is to be used as an additive in conventional cement concrete; however, as the moisture requirements are less stringent for cement concrete than for geopolymer concrete, the excess moisture can be dealt with sufficiently using the techniques developed in this project. This technique can potentially be used for materials other than MFAS generated through flotation such as fly ash that is stored wet to prevent dusting. A third significant accomplishment was demonstrating that the improvement process can help reduce the heavy metal content of fly ash. Specifically, this improvement process was found to reduce the content of all heavy metals in MFAS except for arsenic, and allow the processing water to be reused up to 16 times without resulting in heavy metal accumulation in MFAS (Fig. 2, Table 1). The development of a quality-improvement/recycling system for low-grade fly ash using laboratory equipment is an important preliminary step toward societal implementation of these techniques and is extremely significant.

The vast majority of R&D efforts related to geopolymer concrete being carried out around the world are still in the research stage, with the only example to date of geopolymer concrete use in actual construction being an airport runway in Australia. Research in Japan has been limited to a few examples of geopolymer concrete use in secondary concrete goods such as railroad ties or curbstones. Other significant accomplishments are the demonstration of the potential for developing moderate-temperature-curing geopolymer concrete using MFAS and the generation of basic data that will be useful in development of ready-mixed geopolymer concrete using geopolymers (the demand for which is substantially greater than for concrete products) along with compilation of manufacturing facility-related data and proposal of a system flow for plants to manufacture geopolymer concrete using MFAS cake (Fig. 3).

Application of fly ash improvement technology and geopolymer concrete is particularly promising in Asia where continued use of coal-fired power plants is expected. Implementation of this technology will likely open up the possibility of exporting geopolymer concrete and fly ash improvement technology to developing regions. The export of this technology to China, which generates 47 times the amount of fly ash as Japan and is responsible for 57% of global cement production, will be particularly impactful.

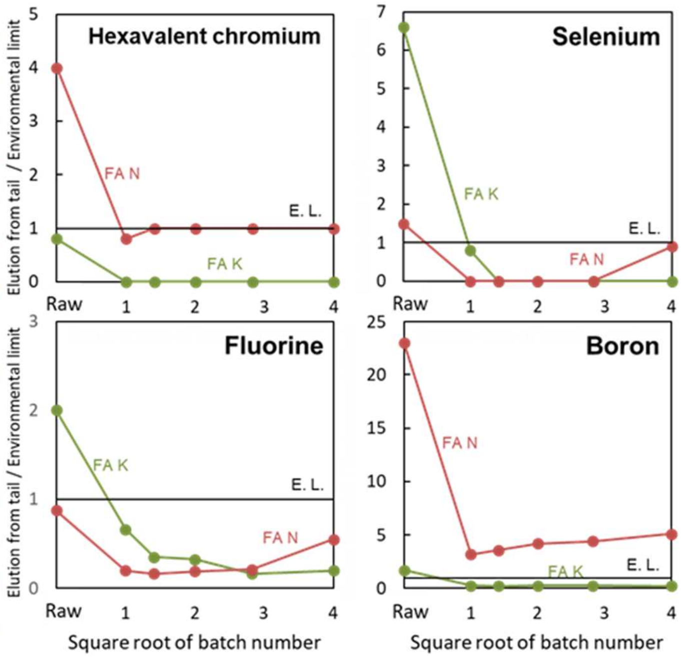

Fig. 2 Heavy metal elution concentration from MFAS when flotation water is reused.

Table 1 Elution of heavy metals in cement-free concrete (mg/L).

Element	Moderate curing temperature type	Japanese environmental standards
Hexavalent chromium	0.02 under	0.05
Selenium	0.005 under	0.01
Arsenic	0.006	0.01
Cadmium	0.005 under	0.01
Lead	0.005 under	0.01
Total mercury	0.0005 under	0.005

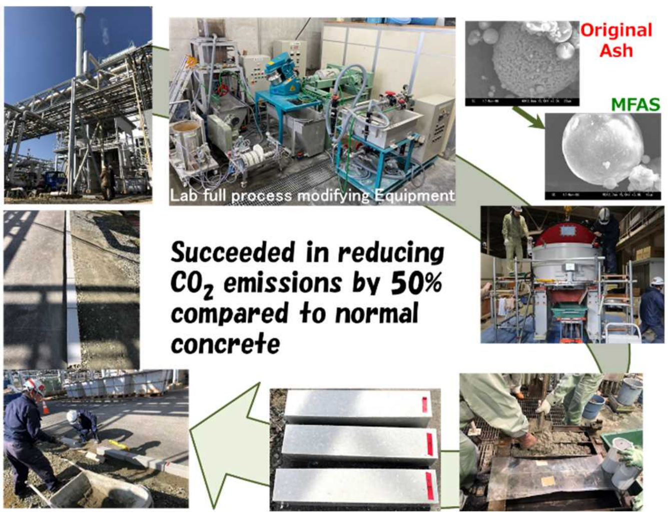

Fig. 3 Cement-free concrete products using the MFAS manufacturing system flow.

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