Biochar-mortar composites for carbon sequestration and environmental application

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In the last decade, a significant amount of research on biochar, a solid by-product from the pyrolysis of biomass, has been conducted due to its role in carbon sequestration, soil fertility and amendment, and water and soil remediation. Biochar has been used in many ways, including for compost, compensatory fertilizers, plant protection, insulation, humidity control, cosmetics, paints, filters, medicine, and energy production. In Korea, barren and sterile areas in slash-and-burn fields in mountainous regions have been dominantly used to improve soil health and crop productivity. Biochar was traditionally synthesized as a form of soot or charcoal using wood and has been used in various ways in everyday life, such as for supplementary heating fuels, cooking, bean paste and soy sauce production, and food storage. Recently, many studies on biochar for environmental and agricultural application have been intensively conducted in South Korea.

In general, construction of buildings and infrastructure using cement-based materials (e.g., concrete) generates huge amounts of CO_2 in the atmosphere from manufacturing to application. Significant effort needs to be made to make the conventional construction industry more competitive in terms of preventing the greenhouse effect and climate change. To compensate for the release of CO_2, it is very desirable to adopt a mitigation process during construction of cement-based buildings and infrastructures. Meanwhile, due to low thermal conductivity and high water holding capacity, biochar has been used as a plaster-mixing material to maintain constant temperature and humidity for wine cellars in European countries. Therefore, it is rationale that mixing biochar with mortar may be a method for creating a carbon sink to store CO_2 in cement-based constructing materials. Additionally, some engineering properties of biochar-mortar composites may be enhanced due to the nature of biochar.

Although some efforts have been made to use biochar as a construction material, attempts to create modern concrete-based construction materials have not been made. In the present study, we hypothesized that biochar may be used as a construction material. Competitive properties of biochar may be favorable for carbon sequestration of biochar in construction materials. We chose mortar as a construction material and added various amounts of biochar for the synthesis of biochar-mortar composites. The physical and chemical properties of the biochar-mortar composites were determined, and their construction and environmental characteristics were examined, including mortar flowability, compressive strength, thermal conductivity, sorption capacity of a volatile contaminant, and toxicity as measured by the toxicity characteristics leaching procedure (TCLP) test and Microtox® bioassay. The optimal biochar-mortar mixing ratio for construction and carbon sequestration purposes was determined.

Compared to rice straw (RS) biochar synthesized in a laboratory, commercial wood chip (WC) biochar has different characteristics. PZC and pH were acidic (6.7 and 6.5, respectively), suggesting that sorption of charged compounds to WC biochar may be different from that of RS biochar. Due to a low pyrolysis temperature, the hydrogen and oxygen contents were also higher than those of RS biochar. Regardless of biochar addition, PZC and pH of biochar-mortar composites were close to those of mortar. By increasing biochar dosage, the carbon content was slightly increased. However, other elements were not significantly changed due to their low contents in the biochar. Compared to the control mortar without biochar, increasing the biochar content resulted in decreasing flowability, probably due to the high water holding capacity of biochar (1.82 mL/g and 1.64 mL/g for RS and WC biochars, respectively). Compared with the initial cone diameter (100 mm), 10% biochar in mortar resulted in a loss of flowability, suggesting that biochar content needs to be less than 10% for construction purposes. Biochar addition also decreased the compressive strength of mortar. As the curing period increased, the compressive strength gradually increased. Compared to the control mortar without biochar, 3% addition of WC biochar to mortar showed 97% and 94% of the compressive strength in 7 days and 28 days, respectively. In contrast, 5% WC biochar significantly decreased compressive strength, showing 59% of the compressive strength of the control mortar without biochar. For RS biochar, 5% addition did not show any decrease of compressive strength. Moreover, after 7 days and 28 days, 5% biochar addition slightly increased the compressive strength, showing 104% and 109% of the control compressive strength, respectively. The advantage of RS biochar addition to mortar in increasing compressive strength remains to be examined. The thermal conductivity of the biochar-mortar composites did not show conclusive trends. It is likely that addition of 5% biochar slightly decreased thermal conductivity from 0.372 ± 0.054 W/m·K to 0.354 ± 0.067 W/m·K. A further increase of biochar to 10% may decrease thermal conductivity to 0.325 ± 0.012 W/m·K. However, considering errors, the effect of biochar on thermal conductivity may not be significant. The average value of biochar-mortar composites is 0.350 W/m·K, which is similar to gypsum.

Sick building syndrome is a serious and increasing concern for residents in condominium complexes in newly developed areas in South Korea. Benzene, toluene, and formaldehyde are well-known volatile contaminants that cause this syndrome. In the presence of the control mortar without biochar, only 9% of the benzene in the gas phase was removed. As biochar was added, the removal of benzene was gradually increased regardless of the biochar type. With 5% and 10% biochar addition, approximately 30% and 40% of the benzene was removed, suggesting that addition of biochar may enhance the removal of benzene from the atmosphere. Due to high surface area and carbon content, it may be favorable for biochar-mortar composites to adsorb gas-phase contaminants in indoor environments. To determine possible toxicity arising from biochar-mortar composites, TCLP tests were conducted. The total organic carbon (TOC) concentration of the leachate after the TCLP procedure was less than 0.05 mg/L. Thus, organic compounds in a TCLP regulation list were excluded. In the two types of biochar, mortar, and biochar-mortar composites (regardless of biochar content), concentrations of inorganic constituents (Se, Ba, Cr, Cd, Pb, As, Ag, and Hg) on the TCLP contaminant lists were by far less than regulatory levels, indicating that the composites are not hazardous materials. Results from the Microtox® bioassay of biochar, mortar, and biochar-mortar composites showed no decrease in luminescence of Vibrio fischeri (data not shown), indicating that there was no toxic effect of biochar-mortar composites to luminous bacteria. These results suggest that the use of biochar-mortar composites for construction materials may be a safe option to reduce the possibility of sick building syndrome without exerting any harmful effects to living creatures in indoor environments.

Our study showed that construction properties of biochar-mortar composites were improved or intact with biochar addition to mortar. Optimal biochar contents were 3%-5% of the initial cement content in mortar. By increasing the biochar dosage in mortar, the removal of benzene from the atmosphere was also enhanced, which may be favorable to prevent sick building syndrome. According to the TCLP tests and Microtox® bioassay, the biochar-mortar composites did not show any toxicity. The results suggest that carbon sequestration in the form of biochar-mortar composites may be a possible and promising approach to mitigate CO_2 rerelease without disturbing the engineering properties of mortar. The effects of biochar on thermal conductivity and sorption mechanisms of benzene to biochar-mortar composites remain to be examined.