Biochar: Conversion of waste biomass to building materials with carbon footprint reduction potential

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Abstract
Purpose of the study was to obtain detailed information on biochar use in building materials and its relation to climate change mitigation in terms of carbon footprint reduction. By using scanning electron microscope, X- ray diffraction, and literature search, phase composition and surface area of biochar were determined and compared to cement. It was found a similarity between biochar and cement, i.e. content of calcite. Also, biochar-containing building materials can directly or indirectly contribute to climate change mitigation.

Keywords
Biochar, building material, carbon footprint, waste biomass.

Introduction
Many of today's challenges are related to the growth of the world population. First, to provide a sufficient amount of food agriculture and livestock farming became more and more intensive. Consequently, all these contribute to environmental changes, which are mainly reflected in soil degradation and deforestation [1, 2]. The growing world population is also contributing to increasing amounts of waste, especially food waste and biomass waste as a result of intensive agriculture [2–4]. These wastes present the main feedstock for biochar production, whose popularity and interest among scientists have only increased in the last ten years [3, 5, 6]. Secondly, population growth increased the need for new buildings in order to provide enough residential and industrial facilities. All of these resulted in soaring consumption of building materials, especially concrete [7].

Most of the past studies mainly focused on biochar as a soil conditioner, while some researched the possibility of using biochar as a dietary supplement in animal feeding, as an adsorbent for heavy metals in wastewater treatments, and also in building materials [8, 9]. The main purposes of biochar application in building materials were to improve the properties of building materials, reduce the consumption of cement and natural aggregates, and for climate change mitigation [10, 11]. Reasons for biochar application in building materials are a shortage of natural aggregates in some parts of the world and cement production as one of the largest sources of anthropogenic CO_2 emissions. They are together with cement main components of concrete [12–14].

Therefore, the main purpose of this research was to obtain detailed information on biochar use in building materials and its relation to climate change mitigation in terms of carbon footprint reduction.

Materials and Methods
Biochar, produced at a pyrolysis temperature of 700 °C, was used for this research. Wood waste from the carpentry was used for biochar production. A cement type CEM I 42.5 N (Salonit Anhovo) was used for this research. A scanning electron microscope (SEM) was used for the morphological determination of the biochar sample. A PANalytical X'Pert PRO diffractometer was used for X-ray diffraction (XRD) analysis to determine possible similarities between cement and biochar samples.

The literature review was made and was limited to articles published from January 2010 to January 2021 and was conducted in different electronic databases. The inclusion and exclusion criteria for the selection of the articles were used.

Results and Discussion
A scanning electron microscope (SEM) was used for the morphological determination of the biochar sample. Its structure is shown in Figure 1 and is presented as a network of extremely small pores, similar to a honeycomb.

XRD analysis of biochar and cement sample are both presented in diffractogram in Figure 2 and provided information about the phase composition of selected materials. The XRD spectra of the cement confirmed the presence of different crystal substances. The most intensive peaks observed at various two theta degrees indicated two major compounds in cement CEM I 42.5 N, i.e. alite (Ca_3SiO_5) and belite (Ca_2SiO_4). The presence of calcite ($CaCO_3$) was also confirmed.

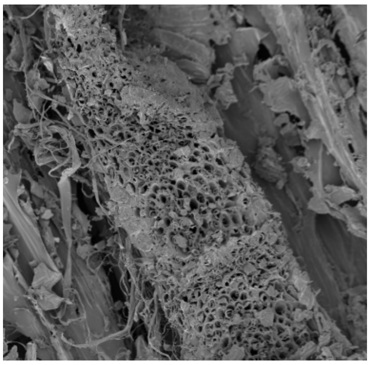

Figure 1. SEM image of biochar sample (× 1000).

Biochar's XRD spectra confirmed the amorphous background where the major content of biochar presented amorphous components. However, some narrow and sharp peaks indicated the presence of calcite but most of the peaks were of less intensity than in the cement sample.

A comparison of cement and biochar diffractograms showed calcite as the main similarity. It was found in the past studies that the content of calcite in biochars depended on the selection of biomass waste for biochar production and pyrolysis temperatures above 500 °C [15, 16]. Interestingly, none of the past studies reported on how could calcite presence in biochar act in cement composites when replacing cement in different dosages. In addition, past studies showed calcite has different functions in cement composites as an active participant in the hydration process and as an inert filler [17].

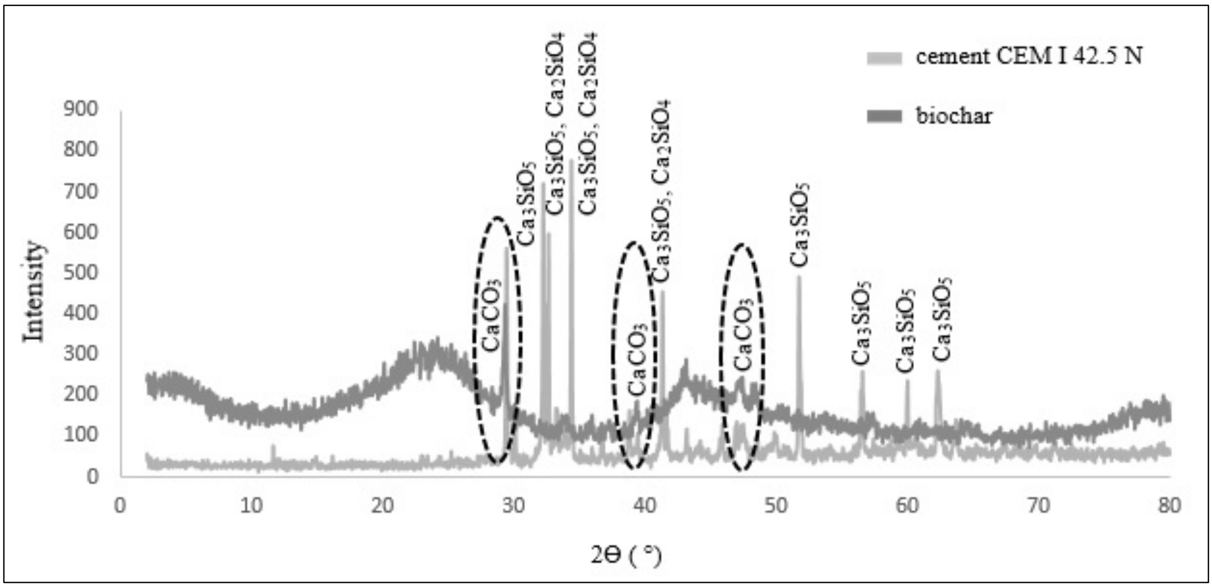

Figure 2. X-ray diffractograms of cement CEM I 42.5 N and biochar.

A literature review was made to obtain information on biochar use in building materials and its relation to climate change mitigation. Most of the selected studies highlighted the importance of biochar dosage in building materials. It was found dosages played the most important role in the findings of the mechanical properties (compressive, flexural, and tensile strength) of biochar-containing building materials and ranged from 0.5% to 40%. Several earlier studies reported increased compressive and flexural strength [18, 19]. Various changes in physical and chemical properties were also found regarding decreased bulk density, increased water absorption, decreased thermal conductivity, and better thermal stability. Additionally, it was found that biochar in building materials acted as micro-reinforcement. Ahmad et al. [20] confirmed that biochar addition modified the fracture surface and change the path of micro cracks.

Selected studies reported biochar-containing building materials can indirectly or directly (CO_2 adsorption) contribute to the reduction of carbon footprint. Indirectly by the reuse of waste biomass for biochar production instead of decomposition in the landfills or incineration process which are both the source of greenhouse gas emissions [21].

Kua et al. [22] reported the capability of biochar-containing building materials to capture CO_2 directly from the air in the pores of biochar in building material and recorded CO_2 adsorption of 0.033 mmol g^{-1} of biochar. In some studies, biochar was saturated with CO_2 before its deployment in the cementitious composite. It was calculated that the average CO_2 adsorption capacity was 1.67 mmol g^{-1} of biochar [23, 24]. Despite the adsorption capability of biochar several studies found that this property may not be useful due to reaching saturation in a relatively short time [11, 25].

Conclusions

All things considered, biochar-containing building materials have great potential in the field of building materials and climate change mitigation. Many studies confirmed the improvement of mechanical, physical, and chemical properties after biochar addition. At the same time, biochar use can indirectly and directly contribute to climate change mitigation. SEM presented biochar's structure playing an important role in direct CO_2 adsorption from the air. In addition, XRD analysis found similarities between cement and biochar both containing calcite. This finding opened some more questions, especially on the importance of selecting biochar with high calcite content when replacing cement in cement composites and how processes inside the composite change. In addition, there is still a huge lack of studies about biochar use in building materials concerning climate change mitigation.

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