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Use of biochar as an additive in concrete

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ABSTRACT

Biochar is a highcarbon product produced by thermal decomposition of organic biomass in an oxygenfree environment. It is mainl y used for soil improvement and fertilization purposes, but this study aims to explore the possibility of using biochar as an addition al benefit to concrete, which is often used as a material to humans. A literature review revealed several studies in which biochar w as successfully used as an additive. The good effect of biochar on the mechanical properties of concrete is based on its nucleation and densification effect, but the internal microstructure, porosity and chemical composition of biochar mainly depend on the raw material, product and production type. These tests include investigating the effect of adding different concentrations and amounts of biochar and the cement substitution level on the new product and concrete material, as well as investigating the cement content and the energy balancing potential for the concrete mix.

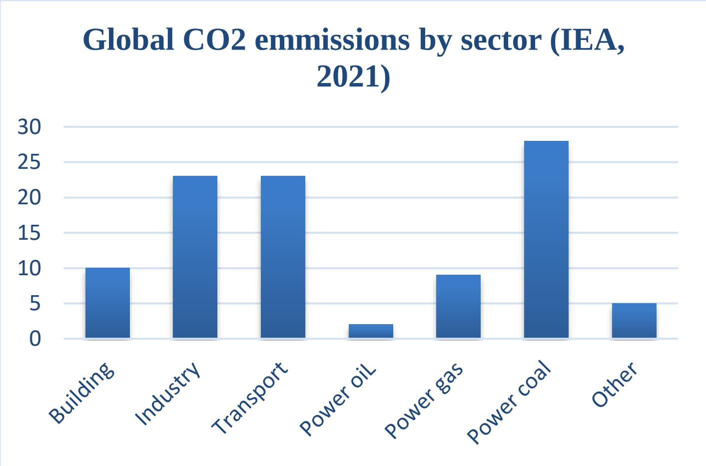
Key Words: *Biochar, Nucleation, Greenhouse Gases, Concrete, Etc.*

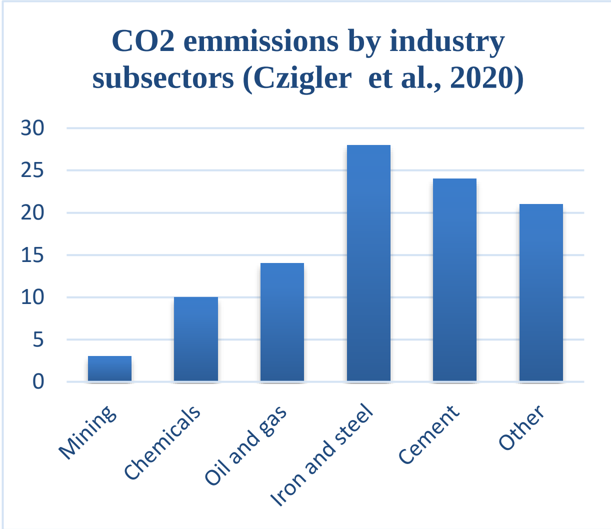
INTRODUCTION:

Carbon dioxide, together with other greenhouse gases, absorbs and emits heat that comes from the warming of Earth's oceans and land surfaces. Although it is not the most harmful greenhouse gas in terms of heat released per molecule, it contributes about two-thirdsof the energy imbalance that causes global warming due to its high concentration and long stay in the atmosphere. The concentration of CO2 in the atmosphere has reached its highest level in 800,000 years at 409.8 parts per million. Anthropogenic sources of carbon dioxide, which are human-made, include the combustion of fossil fuels for energy, land-use changes such as deforestation, and the decomposition of carbonates.

Cement is a crucial component of concrete, which is extensively used in construction. It is primarily responsible for the release of CO2 during the production process. The carbon dioxide emissions occur due to the chemical reaction called calcination, which involves breaking down raw carbonates like limestone into oxides such as lime and CO2. Calcinations accounts for around two-thirds of the total CO2 emissions associated with cement production,while the remaining third is attributed to other necessary processes like power, transportation,and manufacturing.

However, the industrial sector is responsible for about 23% of global CO2 emissions and cement production accounts for a quarter of this. The cement production industry is under pressure to reduce its carbon footprint, which cannot be achieved by altering manufacturing processes or avoiding CO2 emissions during calcination. Therefore, the most effective solution is to reduce cement consumption itself. To achieve this, various alternative methods are being explored, such as partially substituting cement with other pozzolanic materials like silica fume, slag, and fly ash, which are by- products of silicon, steel production, and coal burning. The use of sustainable materials like wood has been proposed as a replacement for concrete in construction. Another sustainable option gaining attention a replacement for cement is biochar, which is produced from carbon-based biomass and organic waste through pyrolysis. While biochar is commonly used in agriculture to improve soil properties, it is also becoming popular in the production of various types of concrete, including normal, pervious, ultra-high performance, and cellular concrete. Several studies have investigated the use of biochar in concrete production.





Over the past ten years, there has been a focus on transitioning to sustainable energy and materials, and as a result, biochar has been the subject of numerous research studies exploring its potential uses in concrete production. This chapter provides an overview of the technology used to produce biochar and its main features, as well as an explanation of how biochar affects the properties of both fresh and hardened concrete.

Production technology and key properties of biochar:
Biochar is a solid substance that contains a high amount of carbon and is formed through the process of pyrolysis. The organic matter used in this process can be wood, food waste, or animal manures, and it is exposed to high temperatures in an environment with low oxygen concentration. The final product has a porous microstructure, a large surface area, andis more resistant to degradation than the source material. This production process involves heating the biomass at temperatures above 400°C, leading to the loss of hydrogen and volatilecarbon molecules, resulting in a more stable carbon mass with some mineral ash and aromaticgroups of molecules.
The process causes the original feedstock material to undergo thermal decomposition, resulting in the production of syngas (which can be utilized for power generation), liquid bio-oils (used for producing biofuels and chemicals) and solid char. The proportion of these products is determined by the conditions under which the pyrolysis is carried out, such as operating temperature, residence time, and the ratio of final products. Pyrolysis can be classified into different categories based on these factors, as outlined by Bridgewater (2012) temperature, residence time and the ratio of final products as follows:

Table: Classification of pyrolysis types based on process conditions and products

Pyrolysis type	Operating temperature	Residence time	Product Weight Percentage (%)		
			Char	Liquid	Gas
Slow pyrolysis	300-500ºC	>10 min	35	30	35
Intermediate pyrolysis	400-500ºC	≈10-30 s	25	50	25
Fast pyrolysis	400-650ºC	≈ 1 – 5 s	12	75	13
Flash pyrolysis	700-1000ºC	< 0.5 s	10	5	85

It is evident that slow or conventional pyrolysis technology is the most suitable for biocharproduction due to its high ratio of solid char production. Since biochar reduction involves the pyrolysis of various organic materials, the source biomass's original structure and composition play a significant role in determining the physical characteristics and microstructure of the final product, i.e., biochar. Despite the significant loss of mass and subsequent shrinkage and volume reduction associated with pyrolysis, the mineral and carbonskeleton of biochar still retains the original material's fundamental structure and porosity, according to Downie et al. (2012).

The physical properties of biochar are not only dependent on the type of biomass used, but are also greatly affected by pretreatment (s uch as drying, pulverization, activation), processing (such as pyrolysis such as heat, residence time, etc.).). and finishing (including gri nding and finishing). Since pyrolysis, the release of organic volatiles and microstructure formation are temperature dependent process es, the maximum processing temperature (HTT) is generally considered the most important factor in the setting of pyrolysis, rather tha n heat, residence time and pressure. A study by Lua et al. (2004) found that biochar samples processed at higher temperatures can exp and the surface area and improve the pore size.

Studies have shown that increased HTT (hydrothermal treatment) leads to greater release of organic volatile matter and higher carbon content in biochar, indicating greater porosity.

This finding was confirmed by an experimental study by Ghani et al. (2013) and Gupta et al. (2018b). The effect of different biomass types and pyrolysis conditions on the properties of biochar used as additive concrete has been extensively investigated as illustrated by the selected examples in the table below. These studies shed light on how the use of biochar in concrete can be in table 2.

Table: Effect of feedstock type and pyrolysis conditions on biochar properties

Reference	Biomass	Pyrolysis conditions	Particle size	Specific gravity	Carbon content	Absorption Capacity
Ghani et al. 2013	Wood saw dust	550-850°C	N/A	N/A	82.3-93.4% wt.	N/A
Khushnood et al. 2016	Hazelnut shell	850°C / 60 min	600 nm	2.20	87.7 % wt.	N/A
	Peanut shell		750 nm	2.35	93.8 % wt.	N/A
Restuccia and Ferro 2016	Hazelnut shell	800°C	N/A	N/A	97.9% wt.	N/A
	Coffee powder		N/A	N/A	82.9% wt.	N/A
Gupta et al. 2017	Wood saw dust	300°C / 45 min	3-200 μm	1.54	68.3%	245 %
Gupta et al. 2018a	Wood saw dust	300°C / 40 min	3-200μm	1.59	62.3 % wt.	735 %
		500°C / 40 min		1.51	87.1 % wt.	878 %
Akthar and Sarmah 2018	Poultry litter	450°C / 20 min	N/A	N/A	19.0 % wt.	N/A
	Rice husk	500°C	N/A	N/A	36.1 % wt.	N/A
	Paper sludge	500°C / 20 min	N/A	N/A	30.0 % wt.	N/A
Cosentino et al. 2018	Softwood	700°C	N/A	N/A	90.2 % wt.	100%

Mechanism of biochar influence on cement hydration and microstructure formation:

The cement hydration kinetics may undergo significant changes when additional cementitious materials or mineral powder admixtures are added. The modifications are caused by different chemical and physical phenomena, depending on the type of additives used.

Effects of Hydration by Chemicals:

When the hydration of cement is affected by chemical modifiers, this is usually due to the pozzolanic activity of the additives. According to ASTM C1221, volcanic ash is a fine material containing silicon dioxide or silicon dioxide and aluminum oxide that reacts with calcium hydroxide in water to form calcium silicate hydrate. It is important to remember that volcanic ash does not react chemically with biochar. Mechanisms of biochar affecting cement hydration and microstructure formation: Cement hydration kinetics can change significantly when adding cementitious materials or mineral powders. The modification is caused by various chemical and physical events, depending on the type of additive hydrate. It is important to remember that volcanic ash does not react chemically with pure water Although biochar usually contains less than 0.5 wt% silica, it is not generally considered a pozzolanic material. However, Zeidabadi et al. (2018) succeeded in increasing the silica content of rice husk and bagasse biochar by up to 13 wt% with a pretreatment including removal of metal impurities with dilute hydrochloric acid.

According to Tavares etal.

(2020), biochar samples made from pretreated rice husk and bagasse biomass meet the criteria to have pozzolanic properties. This sample effectively immobilized 436 mg/g of calcium hydroxide.

Influence on hydration through physical presence:

According to Lawrence et al. (2003) biochar is generally considered a weak chemical additive and its effects on cement hydration and microstructure formation are due to its physical durability. This is called the fill effect and has three ideas: cement dilution, particle size distribution, and nucleation effects. Cement dilution refers to the direct replacement of cement with biochar, thereby reducing the content of hydration products. Because the particle size distribution, or body, contains particles of biochar that will inhabit the voids and replace the entire filling of the stone matrix.

However, biochar has a lower strength compared to other components, which can affect the overall strength of concrete. Finally, bioc har will lead to various nucleation or seeding outcomes.
The above process involves more cement hydration than the hydrates produced by the filler, thus speeding up the process. Biochar's e xcellent water absorption can also reduce the watercement ratio during mixing, which reduces capillary formation and increases water release after the concrete has hardened, resulting in strong rock formation. However, adding biochar to waste may reduce its fluidity a nd increase the need for superplasticizers.
The interface transition zone (ITZ) is the interface between cement paste and aggregate, and its strength and shape also have a signific ant impact on the artificial strength and performance of concrete.
The ITZ's strength depends on various factors such as the shape, size, texture, roughness, porosity, and water absorption properties of aggregates. Aggregates with higher porosity can provide better mechanical interlock between hydration products and aggregate pores, and contribute to increased hydration degree of paste surrounding the aggregate.Biochar particles can also be applied similarly, where a study found better ITZ between biochar and cement paste compared to sand and cement paste. This is due to denser cement paste surrounding biochar particles from enhanced hydration and better mechanical interlock of hydration products penetrating biochar pores.
Gupta et al. (2017) used biochar coating to enhance the mechanical bonding ofpolypropylene (PP) fibers and cement paste. The purpose of the study was to address theissue of small air pockets introduced by PP fibers, which increases the number of capillary pores and air voids. Biochar coating was found to improve the strength and permeability of mortar samples by densifying the mortar paste surrounding the fibers. This was achieved by the absorption of mixing water by biochar, which was released later to promote hydration. Moreover, biochar coating made the surface of PP rougher, promoting friction and enhancing the mechanical bonding of fibers and mortar.

Overall, all of the above-mentioned effects depend on:

- Biochar fineness:
  - Directly related to the particle size distribution in the concrete matrix
  - Finer particles will imply enhanced nucleation
- Biochar content:
  - A higher amount of dispersed particles increase the probability of seeding
  - A higher proportion of relatively weak biochar particles
- Biochar nature:
  - Water absorption and retention properties of biochar
  - The affinity of biochar microstructure to enhance water migration to improve ITZ

Implications for New Materials:

Biochar is said to have a porous microstructure and large surface area, allowing them to absorb water, resulting in a lower watercemen t ratio. A decrease in workability and an increase in the need for superplasticizers were observed in both the mortar and the UHPC wh en biochar was added. In addition, the addition of good biochar material to concrete increases the material and nucleation effect while reducing the water content due to its water absorption and water retention. The finest biochar particles act as additional nucleation site s, providing faster solidification and increased early hydration. These findings were reported in studies by Gupta and colleagues in 20 18 and 2019.
The presence of biochar particles dispersed in the cement and sand mixture can cause product voids that make the matrix denser. This, combined with the absorption of water by the biochar, leads to more cohesion, less bleeding and faster curing due to the lower water-cement ratio. Gupta et al. (2018b) and Dixit et al. (2019) showed improved hydration and increased energy production from biochar.

Effect of Biochar on Materials:

Many researchers have used biochar to improve the mechanical properties and durability of mortars and various types of concrete suc h as highperformance rock, concrete rock and permeable rock. Biochar is used not only as an additive, but also as a substitute for cem ent or sand. In general, the benefits of adding biochar, such as reducing the water-cement ratio due to its high water retention, can improve particle packing and increase hydration, thereby improving the strength of artificial materials of biochar additive concrete. However, the beneficial effect of biochar varies from operation to operation depending on the characteristics of the biochar, but usually does not exceed 5%.

According to various studies (Gupta et al.2017; Cosentino et al., 2018; Gupta et al., 2018b; Qin et al., 2021), nucleation of biochar par ticles can improve particle packaging and increase hydration. Although cement dilution and low strength of the biochar material had a n adverse effect, this effect was reported by Gupta et al., respectively(2018a).

While it is generally believed that an increase in compressive strength causes an increase in the brittleness of the material, it is worth n oting that some researchers have found that the addition of biochar increases the breaking strength. This is because adding good mater ial (biochar) to the waste chemical alters the crack growth process; this comes into play when internal stress breaks the product conne ction, creating cracks. Any irregularity in the concrete mix, such as aggregates, fibers, pores or pores, is generally considered an obsta cle to crack propagation.

Effects on Concrete Performance:

When assessing the strength of concrete, it is important to consider its durability, which is often affected by the microstructure of the c oncrete matrix, such as the size and distribution of pores and their connections. Concrete with a more porous microstructure and high pore connectivity generally does not control, while concrete with less connectivity and finer pore network results in low permeability. Use of biochar in mortar structure also affects the water permeability,with a low amount 12% less slurry and denser mortars are obtai ned, while a high amount (5-8%) is due to its porosity, because there is more porous biochar. particles in the matrix.

One way to determine the quality of concrete is to measure its mass transfer properties by measuring its electrical conductivity. How ever, this measurement is not only affected by the properties of the rock pore network, as it also takes into account the temperature, s aturation, and conductivity of the pore fluid and rock components.Therefore, the addition of new materials such as biochar to the con crete mix is due not only to changes in the pore network, but also to the electronic components of the product.

Like other carbon materials such as carbon powder or graphite nanotubes, biochar is recognized as an excellent material by many res earchers (Singh et al., 2017; Zhang et al., 2014; Jiang et al., 2013; Wang et al., 2013), 2009). In addition, Gabhi et al. (2017) and the work of Cantrell et al. (2012) showed that biochar pyrolysis conditions and raw material materials have a positive effect on the electr ical conductivity of biochar. Thus, the experiments confirmed the relationship between the carbon content of biochar and its electrica l conductivity.

LITERATURE REVIEW:

The performed literature study provided an overview of biochar manufacturing technique and the material's major characteristics, which made it easier to comprehend the basic mechanisms by which biochar affects the properties of fresh and hardened concrete. The prevailing consensus is that biochar is a non-pozzolanic addition that physically prevents cement hydration and the creation of the concrete matrix. To start the process of creating standards and encouraging the use of biochar in concrete mixing, it may be good to have a basic idea of which element has a more significant impact on the mechanical and durability aspects of concrete. The benefits of using biochar include improved cement hydration owing to the nucleation effect and strengthened mortar as a result of a lower effective water to cement ratio caused by high water content. The table below illustrates various previous research works that demonstrate the diverse applications of different types of concrete.

Table : Literature review of some of the authors

Reference	Biomass source	Applications	Biochar Dosage	Major findings
Khushnood et al. 2016	Hazelnut & Peanut shell	Additive in mortar	0.025-1% wt. of cement	• Increase of fracture energy • Improved electromagnetic shielding of concrete
Gupta et al. 2018a	Wood saw dust	Additive in mortar	1-8 % wt. of cement	• Beneficial effect on strength increased with biochar carbon content; w/c ratio • Effect was more apparent for early age
Gupta et al. 2018b	Wood saw dust	Additive in mortar	2 % wt. of cement	• CO2 treatment of biochar resulted in str. Decrease
Ziedabadi et al. 2018	Rise husk & bagasse	Cement replacement in mortar	0-10 % Cement replacement by wt.	• Strength improvement at 5% replacement attributed to the pozzolanic activity of biochar; strength reduction at 10% - due to cement dilution
Mrad & Chchab 2019	N/A	Internal curing agent /sand replacement	0-45% sand replacement by wt.	• General drop of f'c, which was less apparent for air- cured samples implying internal curing properties of biochar
Qin et. al 2021	Eucalyptus Plywood	Cement replacement additive in pervious concrete	0-13.5% cement replacement by wt.	• Increased compressive and splitting tensile str. while keeping permeability properties of pervious concrete
Falliano et al., 2020	N/A	Additive in cellular concrete	0-4 % by wt. of cement	• Decrease in compressive strength, but a slight improvement in fracture energy of air-cured sample
Dixit et al. 2019	Wood saw dust	Cement replacement in UHPC	0-8% cement replacement by wt.	• Effect of biochar particles size: courser particles showed a greater strength reduction • Increased degree of hydration

CONCLUSION:

The main goal of this study was to assess if locally available biochar could be used as a beneficial additive in concrete, as well as to promote the environmental and economic benefits of their application. The results of the experimental study showed that a low dosage of biochar (1.0-2.5% based on %wt. of cement) increases the mortar strength in the level sufficient to compensate for the cement content reduction (up to 20%). High biochar content (up to 15-20%) may considerably increase the early strength of mortar (up to 47% increase depending on the type of biochar). Reducing biochar particles size (through grinding) may enhance the positive effect of biochar application through the increased possibility of nucleation and better particle packing. However, the process may result in the production cost and additional CO2 emissions, which should be taken into account. Biochar can be considered as a promising candidate for the internal curing of mixes with low w/c ratio or samples subjected to harsh curing conditions.

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