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Effect of water entrainment by pre-soaked biochar particles on strength and permeability of cement mortar

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HIGHLIGHTS

- Internal curing in mortar by water entrainment in pores of biochar is proposed.
- Moisture retention and hydration degree are increased due to addition of pre-soaked biochar.
- Increase in mechanical strength is observed in pre-soaked biochar mortar under wet curing and dry curing conditions.
- Improved water tightness is achieved under wet and dry curing due to addition of dry and pre-soaked biochar.

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ABSTRACT

Water retention by biochar makes it a potential material for soil enhancement. However, its application as an internal curing agent in cementitous matrix is relatively unexplored. This study explores addition of pre-soaked biochar on strength and permeability of cement mortar, subject to moist curing and air curing respectively. Biochar was prepared from mixed wood saw dust at pyrolysis temperature of 300 °C (BC 300) and 500 °C (BC 500) respectively. Biochar particles were saturated with water prior to addition in mortar mix at 2 wt% of cement.

Experimental results show that mortar with pre-soaked BC 300 and BC 500 offer 40–50% higher compressive strength at 28-day compared to plain mortar, especially under air curing condition. Similar trend is observed for flexural and split-tensile strength. It is linked to initially low water-cement ratio of mixes with pre-soaked biochar and internal availability of moisture from pores of biochar under external dry condition. Water accessible porosity was reduced by 18–20% due to addition of pre-soaked biochar, that resulted in reduction of sorptivity and depth of water penetration by 55–60%. Overall, significant improvement in mechanical and permeability properties were observed when pre-soaked biochar is used compared to addition of dry biochar in mortar, especially in absence of external moist curing.

The internal curing efficiency of pre-soaked biochar on mortar was found to be higher compared to other mixes, which suggests that it can be a potential curing material for cement mortar. Using biochar as additive in cement mortar also ensures higher waste recycling and carbon sequestration in civil infrastructure while improving strength and durability performance.

1. Introduction

Rising population in cities and rapid urbanization lead to significant increase in the amount of solid waste. For example, in Singapore the amount of waste generated in 2016 is 7.81 million tons, which has increased by 20% compared to 2011 [1]. Significant portion of the total solid waste is generated by the local furniture industry in the form of saw dust. Disposal of saw dust pose a threat to human health because it contains particulate matters that are easily air-borne and cause respiratory problems. Moreover, due to limited land area and push to achieve a zero-waste economy, Singapore encourage alternative use of wood waste to manufacture building materials and other products. Wood waste can be applied as admixture in cementitous composites. Recent studies have explored ash from saw dust as additive in cementitous composites [2,3]. Although it is a means to reduce disposal rate of wood waste, inclusion of ash from saw dust leads to loss in strength of the cementitous matrix [3]. Furthermore, oxidation

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by combustion of wood waste to produce ash is associated with emission of toxic gases and particulates that cause inflammation and cytotoxicity [4].

Increase in recycling rate of wood waste can be achieved by converting it to stable biochar by pyrolysis, which can then be used as admixture in cementitous material [5–8]. Pyrolytic conversion, that takes place in absence of air reduces the emission of greenhouse gases to the atmosphere. Besides waste management, biochar itself is a green material because it sequesters high volume of stable carbon in its structure, which is inherited from the pyrolyzed feedstock. Roberts et al. [9] estimated that depending on preparation condition and biomass used, biochar is capable of reducing net greenhouse gas emission by 870 CO_2 equivalent (CO_2-e) per ton dry feedstock, of which 62–66% are realized from carbon capture and storage by the biomass feedstock of the biochar.

Pyrolysis results in escape of volatiles and organic matters from the biomass, that creates pores of wide size range in the produced biochar. Pores in biochar has been reported to absorb and retain water, that facilitates its use as a soil enhancer [10]. This property can be used to generate internal curing effect in cement mortar by introducing part of mixing water as absorbed water in biochar particles before deployment in the mortar mix. It is akin to application of porous lightweight aggregates (LWA) as internal curing agent in concrete mixes [11–13], although biochar particles are relatively finer than LWA. Fine particle size may be beneficial because it would reduce the spacing factor, meaning that the entrained water after desorption from biochar pores would need to travel shorter distance within the matrix to provide efficient curing [14]. Internal curing takes place by release of pre-absorbed water in the porous particles under humidity gradient, which restores part of water lost due to internal or external drying [15]. It leads to improved hydration and distribution of moisture internally within the cementitous matrix. Although internal curing is widely explored for matrix with low water-cement ratio, it has also been found to be effective for concrete mix with relatively high water-cement ratio (W/C = 0.42) [12]. Espinoza-Hijazin [12] reported that under dry curing conditions, internal curing resulted in improvement of degree of hydration, strength and impermeability by 16%, 19% and 30% respectively compared to reference. Effective internal curing also reduces permeability of concrete [52,53], which restricts access of harmful contaminants into the structure. Thomas [16] reported that internal curing by lightweight aggregate in concrete mixes with W/C = 0.30 and 0.40 resulted in significant reduction of permeability, that was 39% and 29% of the control mix after 1 year and 3 years of curing. It means that internal curing improves the overall performance of cementitous materials even in case of poor external curing.

Nowadays construction projects are becoming fast paced to save time and project cost. As a result, traditional external curing is often difficult to implement, resulting in incomplete hydration and poor serviceability performance of structures. Therefore, the motivation behind this study is to explore biochar as a novel internal curing material for cementitous matrix. It is hypothesized that pre-absorbed water in porous biochar particles can generate internal curing, which would improve mechanical and permeability properties of cement composites.

2. State of the art review on biochar as construction material

There has been a growing interest in application of biochar as additive in cement composites [5–8,17,18]. Gupta et al. [17] discussed important parameters that determine carbon sequestration by biochar particles and its feasibility as construction material. Choi et al. [6] investigated flowability and strength development of cement mortar with hardwood char as cement replacement up to 20% by weight. The findings report that 5% cement replacement by biochar slightly increased 28-day compressive strength without affecting flowability. It was attributed to internal curing of mortar by retained moisture in biochar that reduced moisture loss by evaporation [6]. Khushnood et al. [7] reported increase in flexural toughness and ductile failure pattern of cement paste with 1% addition of biochar from peanut shell and hazelnut shell. The study reported that biochar particles act as obstacle to propagating cracks, thereby dividing them into several finer cracks. It results in increase in fracture energy and improved post-peak behavior under flexure compared to control paste [7,8]. Ahmad et al. [5] reported similar findings with carbonized micro-particles from bamboo used as admixture for high performance self-consolidating cementitous composites. Carbonization of dried bamboo particles were carried out at 850 °C at ramp rate of 1 °C/s. Increase in compressive strength by 30% was observed when 0.20% by weight of carbonized particles was added to cement paste. Introduction of biochar particles increased the tortuosity of crack path, resulting in significant increase of toughness.

Findings from these studies suggest that biochar may be a potential material to improve physical properties of cementitous materials. However, most of the studies focused on mechanical properties cement paste containing biochar as admixture. There is limited information on application of biochar as internal curing agent. Internal curing water by pre-soaking biochar particles may be effective in uniformly distributing moisture and improve mechanical performance and permeability of mortar even in case of limited external curing. Therefore, this article aims to explore influence of pre-soaked biochar on strength and permeability of cementitous mortar under two different curing conditions – wet curing and air curing (27 ± 2 °C and 60 ± 5% RH). Effectiveness of biochar prepared under two different pyrolysis temperatures – 300 °C and 500 °C is studied.

3. Materials and methods

3.1. Cement and sand used

The cement used in this study is ASTM Type I 52.5 N conforming to the requirement of ASTM C150 [19]. The chemical composition and physical properties of the used cement is shown in Table 1.

Locally available river sand with maximum size 4 mm was used in the preparation of mortar. The specific gravity and fineness modulus of the sand was 2.65 and 2.54 respectively. The gradation of the sand conformed to ASTM C33 [20].

Table 1
Properties and chemical composition of cement used in the study.

Properties	Ordinary Portland cement used
Physical properties	
Density (kg/m^3)	3180
Blaine fineness (m^2/kg)	385
Mean particle size (μm)	13.50
Loss in ignition (%)	0.90
Chemical composition (%)	
MgO	1.8
CaO	63.5
SO_3	2.1
Al_2O_3	5.4
SiO_2	20.8
Na_2O	0.59
Chloride	0.005