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Application of biochar from food and wood waste as green admixture for cement mortar

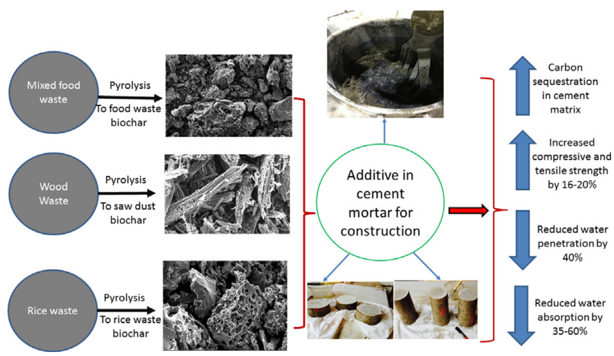
Souradeep Gupta, Harn Wei Kua *, Hui Jun Koh

Department of Building, School of Design and Environment, National University of Singapore, 4 Architectural Drive, (S) 117566, Singapore

HIGHLIGHTS

- Influence of biochar prepared from food and wood waste on fresh and hardened properties of cement mortar is explored.
- Addition of food waste biochar and mixed wood biochar improves compressive strength.
- Mortar with biochar from food and wood waste show higher ductility compared to conventional mortar.
- Sorptivity and resistance to water penetration of mortar is improved due to addition of biochar from food and wood waste.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfilling of food waste due to its low recycling rate is raising serious concerns because of associated soil and water contamination, and emission of methane and other greenhouse gases during the degradation process. This paper explores feasibility of using biochar derived from mixed food waste (FWBC), rice waste (RWBC) and wood waste (mixed wood saw dust, MWBC) as carbon sequestering additive in mortar. RWBC is prepared from boiled plain rice, while FWBC is prepared from combination of rice, meat, and vegetables in fixed proportion. Carbon content in FWBC, RWBC and MWBC were found to be 71%, 66% and 87% by weight respectively. Results show that addition of 1–2 wt% of FWBC and RWBC in mortar results in similar mechanical strength as control mix (without biochar). 1 wt% of FWBC led to 40% and 35% reduction in water penetration and sorptivity respectively, indicating higher impermeability of mortar. Biochar from mixed wood saw dust performed better in terms of mechanical and permeability properties. Increase in compressive strength and tensile strength by up to 20% was recorded, while depth of water penetration and sorptivity was reduced by about 60% and 38% respectively compared to control. Both FWBC and MWBC were found to act as reinforcement to mortar paste, which resulted in higher ductility than control at failure under flexure. This study suggests that biochar from food waste and mixed wood saw dust has the potential to be successfully deployed as additive in cement mortar, which would also promote waste recycling, and sequester high volume carbon in civil infrastructure.

1. Introduction

Increase in the generation of food waste has become a global trend in many industrialized countries (Parfitt et al., 2010). On average, food wastage in South East Asian countries and many parts of the world is estimated to be around 33% (Teng and Trethewie, 2012). For example, in Singapore, 785,500 tons of food waste was generated in 2015, out of which only 13% has been recycled (NEA, 2015). About 681,400 tons of food waste was disposed; this quantity has risen by 50% in the last 10 years and is expected to increase with growth in population and economic activities (NEA, 2015). Elsewhere, in the United Kingdom, a total

* Corresponding author.
E-mail address: bdgkuahw@nus.edu.sg (H.W. Kua).

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of around 15 million tons of food and beverage waste was generated annually, and households are responsible for about 50% of this quantity (Parliament, 2015; WRAP W, 2011)

Two key concerns with food waste generation are the need for landfill sites (Parliament, 2015) and generation of methane – a type of greenhouse gas that is more potent than carbon dioxide – from these sites (Graham-Rowe et al., 2015). Over-reliance on landfill spaces creates a challenge for land-strapped countries like Singapore. Moreover, decomposition of food wastes produces leachate that pollutes ground water (Laner et al., 2012; Goldsmith Jr et al., 2012). Incineration of mixed waste including industrial wastes in oxygen-rich environment produces huge amounts of greenhouse gases and toxic dioxins and furans, which have adverse health and environmental effects (Bordonaba et al., 2011; Thi et al., 2015; Myrin et al., 2014).

Some governing bodies have taken steps to ban direct landfilling of food waste to mitigate the leaching problem (Ju et al., 2016). Although social awareness programs are promoted to encourage minimization of food wastage, low recycling rates of food waste in many countries remain a concern that needs to be addressed. This low recycling rates can be attributed to the fact that segregation of food waste (from other wastes, especially households waste) is still not practiced in many countries (Ju et al., 2016; Yang et al., 2016).

Other than food wastes, another significant type of waste in Singapore and other South East Asian countries is generated from the wood processing industry – in the form of saw dust and wood chips. In 2015, Singapore generated about 530,700 tons of wood waste (NEA, 2015) and these were generated from the abundant furniture factories across the country. A significant portion of it is disposed in landfills or combusted, as about 77% of wood waste and only about 48% of agricultural waste are recycled. To address the low recycling rates food and wood/agricultural waste, this study proposes an alternative way of recycling food and wood/agricultural waste by converting them into biochar and then applied this biochar as admixture in cementitious mortar.

Biochar is produced when organic materials undergo thermal decomposition in an environment with limited availability of oxygen. Biochar has more stabilized carbon content than that of the biomass feedstock from which it is produced, and so the carbon it contains is less likely to be released back into the atmosphere (for example, in the form of carbon dioxide, CO_2). Depending on the type of feedstock and preparation conditions used, biochar has the potential of reducing net greenhouse gas (GHG) emissions by about 870 kg CO_2 equivalent (CO_2-e) per ton dry feedstock throughout its life cycle, of which 62–66% are realized from carbon capture and storage by the biomass feedstock of the biochar (Roberts et al., 2009).

There is a growing interest of using biochar in cementitious composites to improve its physical properties (Gupta and Kua, 2017; Ahmad et al., 2015a; Choi et al., 2012; Khushnood et al., 2016; Restuccia and Ferro, 2016; Gupta et al., 2017b) Gupta and Kua (2018). Khushnood et al. (2016) reported that use of biochar derived from hazelnut shell and peanut shell improved strength of cement paste by as much as 78%, with significant improvement in toughness and fracture energy compared to reference paste. Biochar added at 0.8% by weight of cement was found to deviate the crack trajectory and create a more tortuous crack path before fracture (Khushnood et al., 2016; Restuccia and Ferro, 2016; Restuccia et al., 2017). Besides application as additive, partial replacement of cement by biochar (5% by weight of cement), derived from hardwood is found to improve compressive strength of mortar (Choi et al., 2012). Improvement in strength is realized from water retention capacity and internal curing effect of biochar in cement mortar (Choi et al., 2012). Existing studies (Khushnood et al., 2016; Ahmad et al., 2015b) suggest that biochar has the potential to improve mechanical performance of cement composites by acting as reinforcing material. It is also understood that the fine particles of biochar can introduce filler effect and internal curing, which may improve water tightness of cementitous material through densification and pore-blocking action.

Biochar's characteristics is determined by the production parameters and types of biomass feedstock (Sun et al., 2014). Yang et al. (2016) reported that biochar produced by co-gasification of wood waste and cooked food waste alleviated nutrient holding capacity and acidity of soil, that helped in better plant growth. Similarly, Graber et al. (2010) applied biochar derived from citrus wood in cultivation of tomato and pepper using soilless media. Das et al. (Das et al., 2015a; Das et al., 2017) explored use of wood based biochar as additive in wood/polypropylene composites. Addition of biochar was found to improve flexural strength, fire resistance and thermal stability of composite. Although there are positive outcomes of biochar application in agriculture and in development of polymer composites, there is limited work on influence of char derived from food waste and saw dust (from wood/agricultural waste) on different properties of cement mortar. In Singapore, about 86% of food waste is not recycled. Singapore's National Environment Agency (NEA, 2015) highlighted that food waste contaminates recyclables and decrease the effective waste recycling rate. This study proposes a novel management strategy for mixed food waste and rice waste – collecting and directly pyrolyzing them to produce biochar, which can then be used as construction material. Pyrolysis of these wastes to produce biochar also offers the advantage of requiring smaller footprint/land area required (than landfilling) and reduction of waste volume. This is an important area to investigate, because successful application of these types of biochar in cement composite will effectively increase the overall recycling rate of these waste, while indirectly utilizing civil constructions as means of carbon sequestration.

Therefore, the study aims to explore the use of biochar produced by pyrolysis of mixed food waste, cooked rice and mixed wood saw dust as additive in cement mortar. Effect of addition of each type of biochar on fresh properties of cement mortar including fresh density, air content and flowability, and hardened properties including mechanical strength, *E*-modulus and permeability is studied.

2. Materials, mix design and methods

Locally available materials are used in this study.

2.1. Cement and sand used

Type I Portland cement 52.5 N conforming to specifications stated in ASTM C150 (ASTM, 2016a) is used in this study. Physical and chemical properties of cement are presented in Table 1. The sand used is river sand of fineness modulus of 2.54 and specific gravity of 2.65. Maximum size of sand used is 4 mm, and the gradation conforms to ASTM C33 (ASTM, 2016b).

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
Loss in ignition (%)	0.90
Chemical composition (%)	
Magnesium oxide (MgO)	1.8
Calcium oxide (CaO)	63.5
Sulphur oxide (SO_3)	2.1
Aluminum oxide (Al_2O_3)	5.4
Silicon oxide (SiO_2)	20.8
Sodium oxide (Na_2O)	0.59
Chloride (Cl)	0.005
Main compound (Bogue's equation) (% by weight)	
C_3S	58
C_2S	20
C_3A	2
C_4AF	14