Incorporating Biochar into RCA Concrete for Enhanced 3D Printing Performance: A Review

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ABSTRACT

The biggest challenges of sustainability are to reduce the carbon footprint and minimize the utilization of natural resources. The construction industry is one of the major contributors of the emission of CO2 and produces a lot of waste material. This research aims to review the possible solution to both of these problems. RCA based concrete and 3D concrete printing have proven to be the possible solutions with some demerits of using RCA alone. The properties of Biochar obtained from various research indicates its incorporation into concrete and found it suitable for 3D concrete printing. In this research, suitability and behaviour of biochar is reviewed for its incorporation into RCA concrete for application in 3D concrete printing. Conclusion and research gaps for future study are interpreted and mention thereafter.

Keywords: Biochar, RCA, concrete, 3D printing, sustainability, carbon-negative material

INTRODUCTION

The construction industry produces 40% of the C02 related to energy, as per the Global Alliance for Buildings and Construction 2017. Cement manufacturing alone is responsible for 36% of the emission of CO2 in construction works, and globally, it accounts for 8% of the total anthropogenic emission of CO2 (Habert et al. 2020). The current scenario demands incorporating either carbon-negative materials or helping reduce carbon from the atmosphere. Optimum design and innovative technology are the two most required aspects of the construction industry.[3]

3D concrete printing technology (3D-CP) is one of the innovative ways carbon neutralities can be achieved globally. 3D-CP can construct complex structures quickly and reduce material wastage, thus helping sustainability [1]. One of the significant challenges in 3D-CP is to find a suitable material that can be incorporated with concrete to overcome the limitations of the design mix. Much research has been done on the application of 3D-CP, emphasizing the structure's integrity, composition of materials, and processing methods.

One of the most sustainable green concrete materials found is Recycled coarse aggregate (RCA), which can be used in 3D-CP. Numerous studies concluded that RCA can be used in place of conventional coarse aggregate in 3D-PC at some extent proving its utility to attain carbon-neutrality and reducing waste. It enhances mechanical properties and buildability in the concrete mixture, while reducing the cost and emission of carbon when used in 3D-PC. Falliano et al, stated that aggregate mixture must take care of the dimensional stability (with reference of shape of freshly prepared hybrid concrete). This can be obtained by using some other novel sustainable material like biochar, graphene oxide or any other future admixture (Muthukrishnan et al, 2021).

Recent research has been done on reviewing the effect on adding biochar on basic properties of concrete (like workability, curing, strength properties) (Akinyemi and Adesina 2020; Maljaee et al. 2021). Biochar has been concluded as a good fit with concrete and even with RCA concrete due to its carbon sequestration and reduction the agricultural waste. The compatibility of biochar with cement, asphalt and polymer materials is found suitable for mixing it in concrete for 3D-CP [1-6]. Biochar is basically a waste or residual material of agricultural products which can be obtained from numerous sources like food residual, biomass waste, waste manure etc. The studies on Biochar conclude that it can sequester around 2.00 kg to 3.30 kg of Carbon dioxide (CO2) footprint depending upon locality and waste properties (Azzi et al. 2019). The estimate suggests that 373 million tonnes of Biochar has the potential to sequester 500 million tonnes of carbon dioxide which is 1.5% mitigation of global CO2 emission. (Windeatt et al. 2014; Yang et al. 2019).

All these studies create an urge to develop such materials that can mitigate the upcoming harmful effects that will occur in the environment. To the best of author's knowledge, there is a research gap in reviewing suitability of biochar with RCA Hybrid concrete especially tailored for 3D-CP.

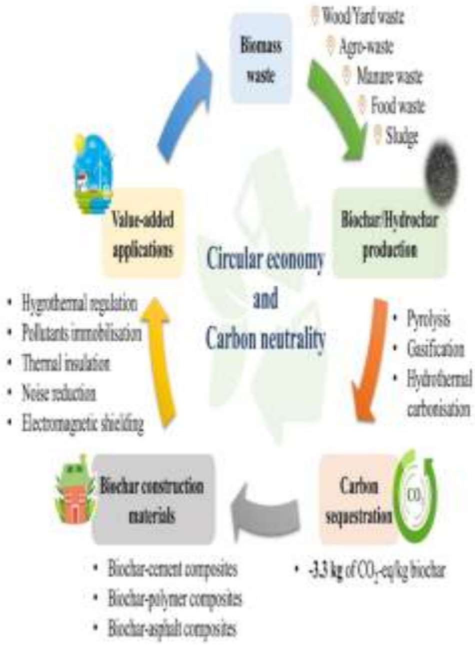


Figure 1: Sustainable waste management towards carbon neutrality [5]

LITERATURE REVIEW

This review study is prepared after carefully studying numerous research papers focusing on RCA, 3D-CP, and Biochar and summarizing the key studies for the need, process, advantages, disadvantage, conclusions and future scope of incorporating Biochar into RCA concrete for enhancing 3D printing performance.

Incorporating coarse aggregates into 3D concrete [1]

In this research, the author studied the suitability of incorporating coarse aggregate into 3D printing. Extrusion based and particle bed concrete printing technologies are studied for suitability of material, process and structure of 3D printed concrete. The 3D printed concrete was also tested for the basic printability requirements such as pumpability, extrudability, buildability and open time. It was concluded that coarse aggregate enhances the buildability, strength parameters (compressive strength, flexure strength, tensile strength, young's modulus) and minimizes anisotropy. The high yield stress and internal friction angle presented challenges for pumpability and extrudability but the main problem was the penetration of paste into coarse aggregate. Future research suggested by this research includes the optimal mixture design and addition of some other novel materials in concrete.

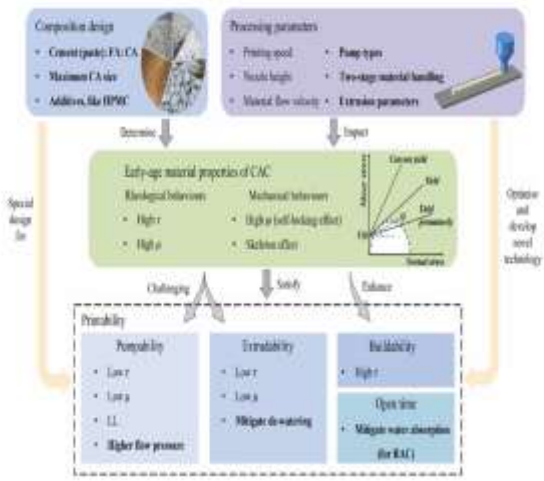


Figure 2: The relationship among material and processing parameters, early-age material properties and printability in 3DPCAC.[1]

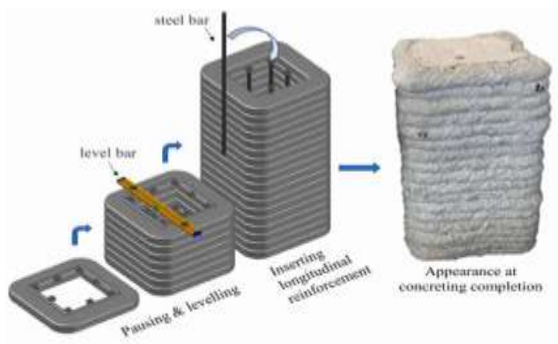


Figure 3: 3D printed CAC structural members and structures.[1]

Data-driven analysis in 3D concrete printing

In this research, existing dataset were used from the published journals for 3D-CP mixtures to examine properties of a concrete like compressive strength, pumping rate, and carbon foot print. Seven machine learning models were analysed systematically for their predictive behaviour. SHAP (Shapely additive explanations) analysis was then performed and presented features of modifying the optimum composition of specified material for 3D-CP application. It was concluded that this methodology is cost-effective, robust, and helps achieving sustainable goals. It was suggested to perform simulation-based research for finding the optimum design mix and suitable composition of targeted material.

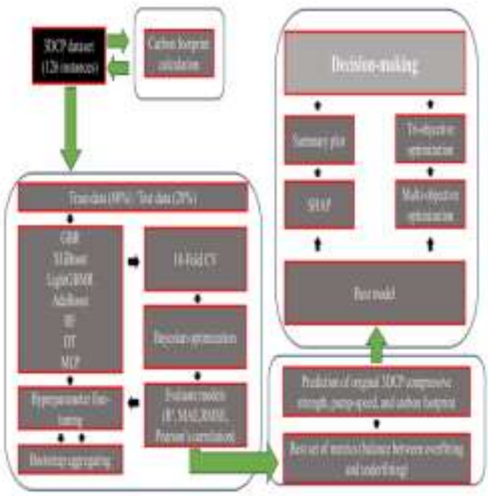


Figure 4: Flowchart of the proposed analysis [2]

Biochar as construction materials for achieving carbon neutrality

The critical review of biochar enhanced mixture is studied in this research for which biochar was incorporated with cement, asphalt and plastic to form the composite material. The main of this research was to study the effect of biochar on the efficiency and mechanism of composite materials. It was concluded that biochar can be a good replacement for matrix material i.e. cement , as well as it can partially replace aggregate in concrete. The study mentioned that biochar mixed concrete helps in reducing carbon footprint and prevent natural resources excessive utilization whilst enhancing behavioural properties of the concrete. Some other benefits of biochar were also described such as hygrothermal utilization, electric and magnetic resistance, contaminant immobilisation, increasing air purity inside the building etc. Suggestions were included for future endeavour such as developing a design mix for physiochemical properties of biochar, validation such designs using FEM simulations, adding biochar to other forms of concrete to produce a carbon negative material. Lastly, biochar was concluded to be suitable as construction material for achieving sustainability objectives.[3]

Figure 6: Types of biochar [3]

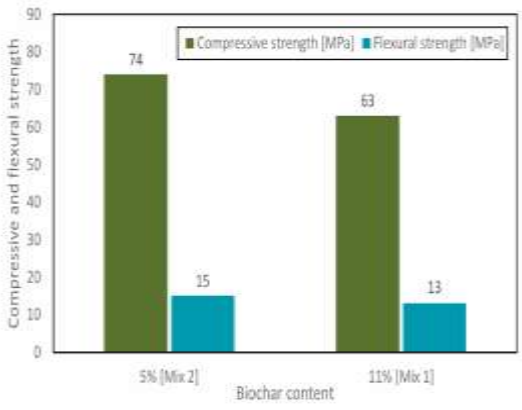
Toward Carbon-Neutral Concrete through Biochar–Cement–Calcium Carbonate Composites

For this research, author combined biochar and calcium carbonate with cement as a carbon storage mechanism to develop a carbon-neutral concrete. The carbon storage mechanism absorbs CO2 from the environment and stores it within the composite material, thus reducing the carbon footprint from the environment. Moreover, this mechanism minimizes the cement content and consequently mitigating CO2 emission. This research identified a favourable compressive strength range of biochar and calcium carbonate mixed concrete. Additionally, it also identified the challenges to scaling such material and provided a guideline of improving carbon-neutral composite and its utility. The conclusion stated that biochar can be used as a replacement of cement, sand, or aggregate within optimum quantity. It was suggested that further work can be done in adopting different kinds of biochar and preparing a predicting machine learning model for the same.[4]

Biochar addition for 3DCP

This study was stated as the first research on obtaining a 3D printable composite materials using biochar with the aim of attaining sustainable environment. It stated that ductility and energy absorption capacity of cement hybrid composite material can be enhanced by adopting micro-sized particles (Ahmad et al, 2015).

The variation in compressive strength and flexural strength were analysed on account of varying biochar/cement proportion, sand/cement proportion, water/cement proportion. The CO2 emission for the specified composites were determined and discussed. It was concluded that addition of biochar helps maintaining dimensional stability of freshly prepared material even at high water/cement ratio due to the good water absorption capacity of biochar. The results stated that 43% CO2 emission is reduced by the most suitable mix design while keeping the compressive strength of at least 60MPa. It was also mentioned that by reducing the biochar content (from 11% to 5% of cement weight), compressive and flexural strengths enhanced by 17% and 15% respectively [5] as shown in Fig.



Effect of biochar content on compressive and flexural strength.

Further research is suggested by combining biochar with other types of concrete like self-compacting concrete, RCA concrete, pervious concrete etc.

RCA and para-wood ash as partial substitutes for NCA and cement in recycled aggregate concrete

This research studied the mechanical properties and chemical composition of RCA (Recycled coarse aggregate), PWA (para-wood ash), and cement by performing experiments. In addition, microstructure analysis was done using scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX). This research stated that RCA reduces concrete properties by up to 15%, although enhancing shear strength and workability. This was the main motivation to induce Para-wood ash (a form of biochar). This study concluded that the strength of composite mortar decreases on mixing RCA and PWA and found significant microstructure effect of PWA and RCA on composition. This research was successful in proposing a predictive equation for mechanical properties using finite element modelling which can accurately predict RCA behaviour, for application in non-structural members of low or medium mechanical strength. This research suggested to explore graphene and other types of biochar and form a hybrid composite for enhanced performance.[6]

Conclusion and Discussion

The basic aim of this study was to critically review the properties and suitability of inducing Biochar in RCA hybrid concrete with the view of applying in 3D printing for its better performance. Following observation are made after conducting this literature review:

i) The sustainability goals can be achieved by increasing the usage of recycled material. RCA with the addition of biochar, is found to be a good fit for this purpose,

ii) 3D RCA concrete printing with the addition of biochar is one of the most promising technologies overcoming the limitation of RCA concrete and 3D concrete printing.

iii) Addition of Biochar in RCA concrete can mitigate the shortcoming of RCA concrete.

iv) Biochar can help in reducing CO2 emission, reduce carbon footprint, enhance RCA concrete properties and increase 3D concrete printing performance.

v) The composition of RCA, Biochar and 3D printing can prevent natural resources, mitigate environmental issues related to CO2 emission, and saves a lot of wastage of material.

Future Scope and Research Gaps

This review study presents the following research gaps and future scope as per the author's knowledge and understanding:

a) Research have been done on suitability of RCA concrete for 3D printing, but there is a clear gap in overcoming the limitation of RCA concrete in 3D printing technology. Further, research is needed to develop a more efficient composite material for the enhanced performance.

b) Researches have been done on one or two types of biochar that are induced in RCA concrete. Future endeavour can look for more types of biochar that can be induced in RCA concrete.

c) All the research are basically aiming for replacing novel materials with conventional material but no work has been done for the optimization of design mix especially tailored for 3D printing technology. Future researchers can develop guideline for the optimizing of biochar and RCA content considering its application in 3d printing.

d) Simulation based finite element studies of composite material of biochar and RCA concrete in found missing. In future, FEM studies on incorporation of different types of biochar with RCA concrete for 3D printing can be done to study the structural behaviour and its suitability in construction industry.

e) Machine learning models for predicting the performance of the composite material can be the future work.

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