



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 7, July 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118



Experimental Study of Pyrolytic Bio-Char Prepared from Sugarcane Bagasse in Civil Applications

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ABSTRACT: Despite efforts to use biochar for road construction, adding biochar to concrete is becoming more and more popular. Comparatively, using biochar in this manner will result in a greater reduction in greenhouse gas emissions than carbon sequestration and capture through mineralization and use in building. This study focused on the impact that bio-chars from sugarcane bagasse pyrolysis have on the mechanical characteristics of composites made of cement. To produce bio-chars, the sugarcane bagasse underwent a thermo-chemical conversion process in a dryer followed by a semi batch pyrolysis reactor. Slurry dewatering was used to create cement-based composites. The findings indicated that compared to sugarcane bagasse, the bio-chars have a rougher structure and a lower amount of poly-saccharides and lignin. Moreover, using 10% by weight of bio-chars enhances cement hydration and the bio-chars absorb 40% less water than sugarcane bagasse. Last but not the least, the mechanical characteristics of composites made from cement demonstrated that bio-chars are promising raw materials for the creation of insulating and reinforced construction materials as a replacement to cement.

KEYWORDS: bio char, sugarcane bagasses, pyrolysis, cement composites.

I. INTRODUCTION

Technologies for direct air capture of carbon dioxide (CO₂) are one of the newest approaches for mitigating climate change and developing of materials that are capable of capturing CO₂ by adsorption is considered as one of the viable options. As a method of carbon capture, adsorption is relatively simple and its associated cost is much lower than commercial processes that are based on, for example, absorption by amine solutions in wet scrubbing systems [1]. Composites materials, used in civil construction, are a combination of an inorganic matrix (mainly cement) reinforced by other components (vegetable, carbon, glass or steel fibers), which leads to a finished material with higher properties than the starting constituents [2]. Biochar, with its strong affinity for nonpolar substances and high surface area, can be a potential material to capture and store CO₂ by adsorption in its pores. It has been widely applied as soil conditioner and as a treatment material for wastewater, but research on its application as a construction material is still sparse. Because of its ability to capture CO₂ from air, bio-char has the potential to contribute to lowering of carbon emission in the building industry if it is used as a construction material. Biochar was used to replace up to 50% of plaster mixture, with the rest comprising clay, cement mortar, and lime. Biochar has also been used to develop lightweight biochar-concrete panels, biochar-lime bricks, plaster, and tile adhesives [3]. Preliminary findings suggest that this biochar-plaster composite provides excellent insulation, and is able to maintain the desired indoor humidity [4]. The composite may prevent the indoor air from becoming too dry, which is one of the main causes of respiratory problems; it may also prevent condensation on the outer walls, which might otherwise cause mould growth.

The use of sugarcane bagasses feedstock as raw materials for pyrolysis could be interesting to produce bio-chars for the reinforcement of the cement matrix. Indeed, the pyrolysis, which is a thermo-chemical conversion process of the biomass, permits to decompose the lignin, cellulose and hemicelluloses into three mainly products; bio-char, bio-oil and non-condensable gases [5]. Knowing that lignin and hemicelluloses are prejudicial to the hydration of cement (in the case of vegetable fibers), the bio-chars will be an attractive product for an application in cement-based materials [6]. For applications in building materials, Akhtar and Sarmah (2018) studied the influence of bio-chars from rice husk or paper



mill sludge on the mechanical property of concrete. The partial replacement of cement up to 0.1% by volume of bio-chars improves the flexural and splitting tensile strength of concrete [7]. Gupta et al. (2018) studied the effect of the addition of bio-chars from wood saw dust on the physical and mechanical properties of mortars [1]. The authors sowed that the addition of bio-chars up to 2% by weight modifies the cement hydration due to the filler effect of the particles. Moreover, the biochars decrease the density of mortar due to the porous structure and low density of the particles. However, the flexural strength did not significantly affected by the addition of bio-chars. However there is a lack of study on the use of bio-chars in cement based materials for thermal applications.

The aim of this study is to primarily characterize the bio-chars resulting of the pyrolysis of sugarcane bagasse using several techniques such as Scanning Electron Microscopy (SEM), Fourier Transform infrared spectroscopy (FTIR) and Mechanical load tastings. Secondly, determine the effect of the bio-chars content on the mechanical properties of cement-based composites for a potential application in building materials.

II. MATERIALS AND METHODS

A. Materials (Feed stock –Sugarcane baggases)

The sugarcane bagasse, a fibrous waste left after sugarcane stalk (*Saccharum officinarum*) juice extraction, was obtained from Bhubaneswar locality as shown in Figure 1 (a). Dried raw sugarcane bagasse was crushed to a diameter less than 0.4 mm using a knife then, sieved between 0.2 and 1mm of diameter in a horizontal sieve shaker. The sugarcane bagasse was submitted to a thermo-chemical conversion process in a batch pyrolysis reactor to prepare the biochar as shown in Figure 1(b).



Fig.1 (a) Waste sugarcane Baggases



(b) Bio chars after Pyrolysis

To obtain a higher quantity of bio-chars, a pyrolysis was adopted with a residence time of 4 hr at 300 °C and a heating rate of 20 °C/min. This pyrolysis process provides the best compromise between mass loss and degradation of sugars in case of sugarcane bagasse. The cement used in this study was Ordinary pozolanic cement (OPC) type .The chemical composition and physical properties of the cement are shown in Table 1.

Table 1 Composition and physical properties of the cement used

Chemical composition (By wt. %)	
SiO2	24.66
Fe2O3	5.04
AL2O3	7.06
CaO	55.70
Na2O	0.29
Density (g/cm3)	3.05
Particle size (micron)	15.06

B.Composites preparation

Cement-based composites containing bio-chars, ranging from 2 to 6% by weight regarding constant amount of cement, were prepared using slurry vacuum de-watering process. This method is a reproduction, at laboratory scale. Cement, bio-chars and water were mixed with an initial water/cement ratio equal to 0.8 during 5 min then the mix was introduced in a casting box (190x200 mm²). To remove excess water, the casting box was placed under vacuum during 10 min. After, pads were pressed at 0.5 MPa for 5 min.



Fig. 2 Cement-based composites containing bio-chars

However, a lower compressive strength was applied to increase the porosity and consequently improve the properties of the material. After being removed from the box, the specimens were sealed in plastic bag to cure at saturated air at 23 °C for 1 day. Then, the pads were introduced in a climatic chamber at 23 °C and 50% of relative humidity for 28 and 90 days of curing to study their behavior at short and medium terms. A diamond disk cooled by water was used to cut pads (120mmx35 mm) for flexural tests, after curing. Thickness of samples varies between 11 to 16mm in accordance to bio-chars content.

C.Methods

2.3.1 Bio-char and cement composite Characterization

Scanning electron microscopy (SEM) images of the sugarcane bagasse and bio-chars were obtained from IIT Bhubaneswar. Fourier transformed infrared spectra (FTIR) of sugarcane bagasse and the bio-char was done at VSSUT,Burla.The samples of concrete based biochar composites were prepared in GIFT, Bhubaneswar laboratories. After curing (28 and 90 days) under controlled conditions (25 °C and 50% relative humidity), cement-based composites were characterized by physical and mechanical tests.

(a) Physical properties

For all samples, the apparent porosity was determined according to (ASTM C 948, 2009). The apparent porosity of composites was determined by the following equation:

$$\text{Apparent porosity} = [(B - C) / (B - A)] \times 100 \tag{1}$$

With A=immersed mass (g), B=saturated surface dry mass (g) and C=oven dry mass (g).

(b) Flexural strength

The flexural strength of bio-chars/cement-based composites was determined to evaluate the potential application of the materials in building construction. Three-point bending tests was carried out using a universal testing machine model 3367 (Instron, France) with a 500 N cell, a crosshead speed of 0.5 mm/min and a span of 100 mm. Flexural strength (FS), Modulus of elasticity (MOE), Toughness (TE) and limit of proportionality (LOP) of composites was calculated according the following equations (Tonoli et al., 2009):

$$FS = (3 \cdot F_{max} \cdot S) / (2 \cdot w \cdot d^2) \tag{2}$$

$$MOE = (S^3 \cdot m) / (4 \cdot w \cdot d^3) \tag{3}$$

$$TE = \text{absorbed energy} / (w \cdot d) \tag{4}$$

$$LOP = (3 \cdot FLOP \cdot S) / (2 \cdot w \cdot d^2) \quad (5)$$

Where F_{max} is the maximum load (N), FLOP is the load at the upper point of the linear portion of the load versus displacement curve (N), S is the span (mm), w and d are the specimen width and depth respectively (mm), m is the tangent of the slope angle of the load versus displacement curve during elastic deformation, absorbed energy is the integration of the area below the load vs. deflection curve at the point corresponding to a reduction in load carrying capacity to 30% of the maximum reached. Four samples are used to determine the average of flexural strength and standard deviation

III. RESULTS AND DISCUSSION

A. Morphology of bio chars

Fig. 3 shows pictures obtained by the scanning electron microscopy (SEM) of the sugarcane bagasse in bio-chars form. Sugarcane bagasse show particles consisting of individual fibers associated in the longitudinal direction, which are parallel to each other. The thermo-chemical conversion process breaks the cell wall of the unitary fiber of sugarcane bagasse, which opens and gives back a rough appearance to the bio-char. This roughness is a characteristic of biochars that can promote the adhesion between the bio-chars and the cement matrix (Mukhopadhyay and Fangueiro, 2009).

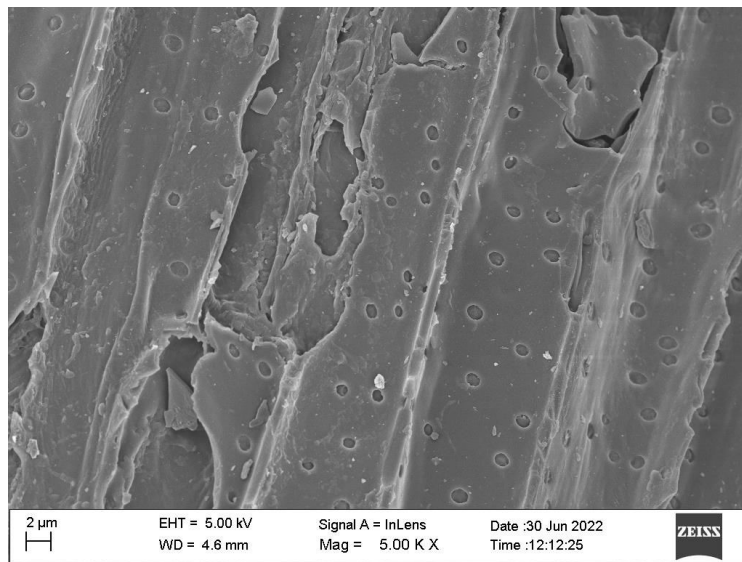


Fig. 3 SEM of the sugarcane bagasse bio-chars.

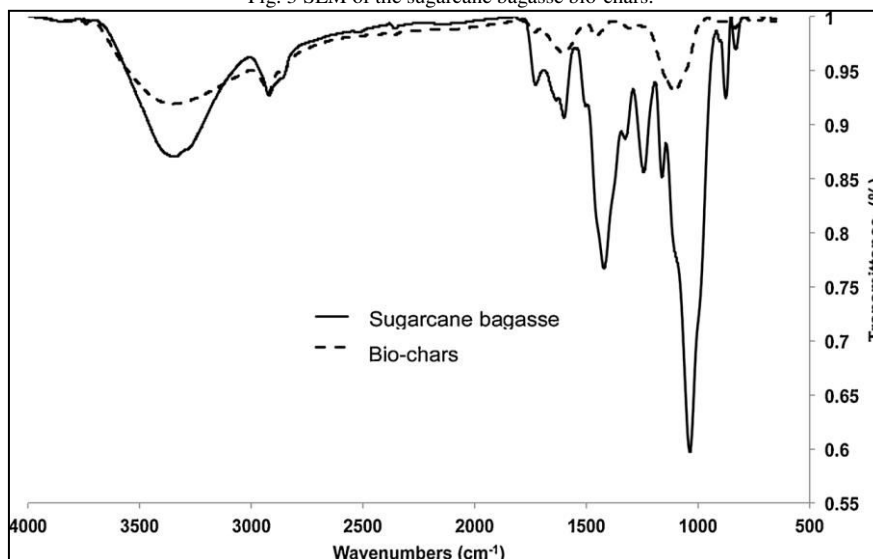


Fig. 4 FTIR spectra of the sugarcane bagasse and bio-chars.

Fig. 4 shows Fourier transformed infrared spectra (FTIR) of sugarcane bagasse and the bio-char. The spectrum of sugarcane bagasse presents carbohydrates characteristic signals (cellulose and hemicelluloses) and lignin signals located towards (Bilba and Ouensanga, 1996). After the thermo-chemical conversion process, a decrease of the intensity of all the signals is denoted except for the one located at 2921-2891 cm^{-1} corresponding to the vibration of elongation of the aromatic C-H bond. Decreases of 65 and 90% and of the intensity of the signals corresponding to lignin and polysaccharides respectively indicate that thermo-chemical conversion process of sugarcane bagasse affects more polysaccharides.

These observations suggest structural modifications of the sugarcane bagasse after the pyrolysis. The decrease of the intensity of specific signals such as polysaccharides or lignin, involves a decrease of their content in the component. Indeed, it has been shown that the cross-linking decreases the lignin content as it is transformed into pseudo-lignin (Bourgois et al., 1989). The polysaccharides are known to retard the hydration of the cement; the reduction of amount of polysaccharides is a good parameter for the use of bio-chars in cement based materials.

IV. CONCLUSION

Based on the experimental results obtained in this study, the following conclusions can be drawn:

- The scanning electron microscopy showed that the bio-char presents a rough surface that could increase its adhesion to the cement matrix.
- The Fourier transformed infrared spectra of bio-chars showed that the thermo chemical conversion of sugarcane bagasse modifies the structure forming bio-chars with lower polysaccharide and lignin content.
- The water absorption tests showed that bio-chars absorb lower quantity of water than sugarcane bagasse.
- The flexural strength tests showed that cement-based composites containing bio-chars and sugarcane bagasse present similar mechanical performances.

According to the results of the study, the bio-chars present a huge potential for the elaboration of insulating building materials to reduce the energy consumption of building construction.

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Impact Factor: 8.118



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