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Sustainable Recycling of Waste Epoxy, Biomass and Its Blends as Alternative Reductants for Hematite Using Microwave Technology

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Abstract:

The circular economy demands that products are reused, recycled or reproduced into another product for a sustainable environment. The rising amount of greenhouse gases in the atmosphere calls for clean fuels to be used in production. Biomass is known to contain a considerable amount of carbon likewise, epoxy which is a thermosetting plastic. Laboratory studies on the use of waste epoxy, bamboo and coconut shells (CNS) as reductants were performed on reagent grade ferric oxide (96.89 wt. % Fe_2O_3) using a domestic microwave oven of 1400 W power rating. Composite pellets of 30% and 70% were formed from the mixtures of ferric oxide and carbonaceous materials respectively. The composite pellets were fired in a microwave oven for 30 minutes. The percent mass loss and extent of reduction were then calculated after firing. The results depict that metallic iron can be produced effectively using epoxy, bamboo, CNS and their blends as reducing agents. Analysis of the results indicates a blend of 35 % Bamboo, 35 % CNS and 30 % epoxy attained the highest reduction of 95.41 %, which was closely followed by a blend 30 % epoxy and 70 % CNS of 92.92 %. The individual carbonaceous materials also recorded significant reduction of 74.76 %, 78.22 % and 83.65 % for bamboo, CNS, and epoxy respectively. From the laboratory results obtained, waste epoxy, coconut shells and bamboo can be recycled in an eco-friendly and sustainable manner through their usage as an alternative reductant for ferric oxide. Also, the success achieved with reduction in the microwave environment can catalyse the gradual shift from the conventional blast furnace used in iron production.

Keywords: Bamboo, CNS, epoxy, ferric oxide, microwave oven

1 Introduction

Bamboo shares a number of desirable fuel characteristics with other bioenergy feedstock such as low ash content and alkali index. Its heating value is lower than many woody biomass feedstocks, but higher than most agricultural residues, grasses, and straws. Although, non-fuel applications of bamboo biomass may be more profitable than energy recovery, there may also be potential for co-production of bioenergy together with other bamboo processing [1]. Bamboo waste has the potential to be applied in applications which can utilize the carbon and hydrogen content in the biomass for valuable products instead of being burnt which contaminate the surrounding environment as well as increasing global warming [2].

Coconut shells (CNS) are inexpensive and abundantly available solid waste material that is cultivated in several parts of Ghana, mainly along the coastal belts [3]. CNS can be used as a material to produce briquettes, and no trees have to be felled to access them, either. Hence the deforestation will be greatly reduced with the increasing use of coconut shell as charcoal for the industry. Additionally, it is known by research that coconut shells can be used in a variety of applications such as biosorbent for Ag ion sorption, soil covers for protection, reinforced polymer media, cement amalgams for construction etc. [4]

Epoxy is the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins a general term used to, also known as polyepoxides are a class of reactive prepolymer and polymers which contain epoxide groups. Epoxy resins typically contain a three-membered ring with -O- atom. Different terminologies are also used to specify the group such as epoxide, oxirane and ethoxyline group, R-CH(O)-CH_2 [5].

CNS and Bamboo are biomass materials which are available in large quantities in tropical countries and from being one of the fastest growing plants respectively. Waste Bamboo and CNS are renewable and carbon neutral fuels because the amount of CO_2 given off during combustion is the same as that which was picked up from the atmosphere during photosynthesis. Epoxy, however, is widely used in small boats, aeroplanes, metal coating, electronic and electrical equipment; as such it is a component of e-waste [5].

Microwave energy is a nonionizing electromagnetic radiation with frequencies in the radius of 300 MHz to 300 GHz [6]. Microwaves correspond to electromagnetic waves of wavelength from 1 mm to 1 m. The use of microwaves to heat minerals is dated as early as 1967 when microwave energy was applied to the heating of several reagent grade metal oxides and sulphides [6].

The use of postconsumer polymers as reducing agent and carburisers is gaining attention with its usage in metal production by various researchers [7-13], however, literature on the use of bamboo, CNS and epoxy as feedstock for iron and steel making technologies in microwave oven is limited [14].

The aim of this present work seeks to investigate the feasibility of using epoxy, bamboo, CNS and its blends to reduce hematite in a microwave environment.

2 Experimental

2.1. Raw Materials

Pulverised reagent grade hematite from BDH chemicals limited, Poole- England (96.89 wt. % Fe_2O_3) was used. Its chemical composition as determined by XRF analysis is given in Table 1. Dried bamboo and CNS, collected from Takoradi (Ghana) served as a source of biomass materials. The chemical composition (wt %) of the samples and the ash analyses are given in Tables 2-3. Epoxy was also collected from Tarkwa, Ghana.

Component	Fe_2O_3	SiO_2	CaO	MnO	ZnO	TiO_2	SO_3	LOI
Composition (wt %)	96.89	0.445	0.0225	0.020	0.0115	0.134	0.257	2.22

Table 1: Chemical Composition (XRF) of Iron Ore [15]

Table 2 and 3 present the elemental and proximate analysis of CNS.

Component	C	H	S	N	O*
CNS Raw (wt. %)	52.4	5.72	0.03	0.11	41.77
CNS Char (wt. %)	78.1	3.49	0.01	0.15	17.55

Table 2: Elemental Analysis of CNS [3]

* By Difference

Component	Raw (wt. %)	Char (wt. %)
Moisture	8.5	5.40
Ash*	0.87	0.70
Volatile matter*	87.5	29.80
Fixed carbon*	11.6	69.60

Table 3: Proximate Analysis of CNS [3]

* Dry Basis

Analysis of raw CNS ash content is presented in Table 4

Component	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	P_2O_5	Mn_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	V_2O_5	ZnO	BaO	SrO
Raw (wt %)	37.5	1.8	1.8	0.29	3.1	0.07	6.2	4.2	3.7	23.2	5.2	1.7	2.4	0.56	0.12

Table 4: Ash analysis of Raw CNS [7]

Below is Table 5 which presents the elemental analysis conducted on the charred bamboo used for the laboratory work.

Element (K-series)	Weight %	Atomic %
C	72.20	82.20
O	15.96	13.55
K	8.98	3.12
Si	1.99	0.96
P	0.28	0.12
Al	0.08	0.04

Table 5: Elemental Analysis of Charred Bamboo

A scanning electron microscope analysis of the charred bamboo indicate its amorphous nature. Figure 1 depicts a Scanning Electron Micrograph of the charred bamboo.

Figure 1: Scanning Electron Micrograph of Charred Bamboo

2.2. Experimental Procedure

Biomass was washed-off of dirt and dried. After drying, samples were charred in an oven in a reduced environment since by means of charring; the material is burnt in a low oxygen environment to drive off volatile compounds.

Composite pellets of various blends of biomass and epoxy with the pulverised ferric oxide were formed. The pseudo-spherical pellet composed of 70 % of iron oxide, and 30 % carbonaceous materials. The 30 % carbonaceous material may contain 100 % of bamboo, coconut shell or epoxy and various blends of the carbonaceous materials were used. Table 6 gives the brief sample composition with their names. Add the next paragraph Pellets were dried in an oven for an hour at a temperature of 110 °C to remove the physically held water from the samples after been left to cure for 72 hours in the laboratory.

Pioneer microwave model PM-25L of maximum power rating 1400 W and frequency 2450 MHz was used in the firing of the pellets. Based on preliminary works, it was ascertained that a good extent of reduction was achieved using the maximum power rating efficiency of 100 % (I remember it's up to 100%) for 30 minutes.

Sample	Composition
A	5.6 g Fe ₂ O ₃ , 3.2 g of Bamboo (100 %)
B	5.6 g Fe ₂ O ₃ , 3.2 g of CNS (100 %)
C	5.6 g Fe ₂ O ₃ , 3.2 g of Epoxy (100 %)
D ₁	5.6 g Fe ₂ O ₃ , 2.24 g of Bamboo (70 %), 0.96g of CNS (30 %)
D ₂	5.6 g Fe ₂ O ₃ , 0.96 g of Bamboo (30%), 2.24 g of CNS (70%)
E ₁	5.6 g Fe ₂ O ₃ , 2.24 g of Bamboo (70 %), 0.96 g of Epoxy (30 %)
E ₂	5.6 g Fe ₂ O ₃ , 0.96 g of Bamboo (30 %), 2.24 g of CNS (70 %)
F ₁	5.6 g Fe ₂ O ₃ , 2.24 g of CNS (70%), 0.96g of Epoxy (30%)
F ₂	5.6 g Fe ₂ O ₃ , 0.96 g of CNS (30 %), 2.24 g of Epoxy (70 %)
G	5.6 g Fe ₂ O ₃ , 1.12 g Bamboo (35 %), 1.12 g CNS (35 %), 0.96 g Epoxy (30 %),

Table 6: Sample Name and Composition (Hematite and Carbonaceous Materials)

3. Experimental Results

3.1. Nature of Pellets before and After Firing

The pellets appear to change in size and appearance which was noted to be a possible indication of a reduction. The reduced pellets were attracted by a magnet which also indicates that hematite was reduced to either magnetite or metallic iron (α -Fe). Figures a, b, c and d are sample green pellet, pellet being fired in a microwave oven, pellet after it has been fired and a pellet attracted to a magnet respectively.

Figure 2

3.2. Extent of Reduction

The various dried samples were weighed before and after firing to ascertain the percent mass loss and the percent reduction. The percent or extent of reduction was calculated from the oxygen content of the reduced metal produced from the reaction of the iron oxide with each carbonaceous material [3, 7].

Figure 3: Extent of Reduction of Samples

4. Conclusion

A laboratory investigation to recycle waste epoxy, bamboo, and CNS and its blends as an alternative reductant for hematite in a microwave environment has been ascertained. The major findings of this investigation are:

- Blends of epoxy, bamboo and CNS could be used as a reducing agent for hematite.
- The use of microwave energy could be used to reduce hematite to metallic iron, a step in moving from the traditional blast furnace of iron and steel making.
- It was observed that epoxy showed the highest extent of reduction among the three carbonaceous materials.
- The extent of reduction improves considerably with blends of epoxy with a blend of bamboo, CNS and epoxy recording the highest reduction of 95.41 %.

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