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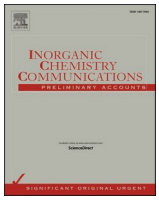

Chemical preparation and evaluation of the physicomechanical properties of novel copper–water hyacinth nanocomposite

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ABSTRACT

Water hyacinth has become a menace in many rivers in Ghana and the world at large. Various methods applied to get rid of these invasive plants have been unsuccessful. One workable solution is to use the plant for economic benefit. We have synthesized Copper-Water Hyacinth nanocomposite using the chemical reduction method. This is a preliminary research stage to ultimately use the properties of the material to construct a filter to treat water.

The nanocomposite was characterized by Transmission Electron Microscopy which revealed the morphology and other surface features with particle sizes ranging between 3 and 10 nm. Electron diffraction studies confirmed the planes (200) and (311) as well as the presence of metal copper.

X-ray Diffraction studies confirmed the Miller indices for the angles 21.7°, 25.3° and 45° as (111), (200), (311). With the application of the Tinius Olsen IT 406 High Energy Pendulum Impact Machine, the mechanical durability of the nanocomposites was tested to determine the impact resistance. The mechanical impact energy of 27.98 ± 0.02J was similar to natural fiber-reinforced composites. Direct current Ohm's bridge was employed to investigate the electrical conductivity, resistivity and electric field strength, and the values were $(3.64 \pm 0.02)x10^{-2}(\Omega m)^{-1}$, $27.50 \pm 0.02\Omega m$, $224.17 \pm 0.02 Vm^{-1}$ accordingly. Copper-Water Hyacinth nanocomposite could be compared to intrinsic semiconductors owing to the electrical conductivity value. The percentage of moisture content led to an increase in the applied voltage. The Infrared (IR) Spectroscopy data also suggests that they have a high potential for use as ion adsorbent materials in aqueous chemical systems.

1. Introduction

Natural Fiber Reinforced Composites are relevant to the industry especially in mechanical, electrical, and thermal applications in contrast to Synthetic Fiber Reinforced Composites which are robust, environmentally stable, and have long fatigue life despite their vulnerability to environmental damage when exposed to temperature, humidity, and ultraviolet radiation (UV).

Copper nanoparticles are effectively stabilized by high molecular molecules [1,2] such as chitosan, cellulose, arabinogalactan and other natural and synthetic compounds such as poly-N-vinylpyrrolidone, polyacrylamide, poly-N-vinyl-1,2,4-triazole, and others [3,4,5,6].

Novel Metal Nanoparticle-Cellulose Fiber Composites is undergoing scientific examination and advancement as a result of their exceptional engineering properties such as thermal insulation, corrosion and wear resistance and electrical conductivity [7]. Moreover, the increase in environmental consciousness has compelled Governments to enact strict laws thereby encouraging researchers to try new natural ecofriendly Nanocomposites. These Nanocomposites are prepared by using eco-friendly material procedures in conjunction with nanofillers to biopolymers with highly promising products that exhibit better properties to preserve the material biodegradability, environmental friendliness, easy processing, remarkable physicomechanical properties, avoiding eco-toxicity. Scientific investigation is underway to get biodegradable reinforcing fillers to achieve the improved function of composites, and cellulose fillers from natural fibers are expected candidates [8].

To further increase this environmental awareness, Water hyacinth (Eichhornia crassipes), one of the plentiful water plant species is under investigation as a possible natural fiber. This invasive, aquatic plant discovered in tropical and subtropical regions such as Asia, South

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America, North America, Central America, Africa, and Oceania is a serious problem to the environment [9]. It is acknowledged to hinder irrigation and hydropower systems, obstructing river waters and canals. It is a comfortable host and reproduction ground for disease-spreading insects, increasing evapotranspiration whilst reducing biodiversity. Chemical, biological and mechanical methods involving a considerable amount of money by Governments to rid them of their habitats have achieved very little success. Moreover, some of the approaches of removal have proven to be counterproductive resulting in contamination to the environment and elimination of other beneficial plants. Therefore, its removal and promotion into sustainable livelihood use have gained a major interest. Current reports have confirmed that this plant possesses a high fiber content and has a high proportion of cellulose in its shoot and roots [10].

The ability of E. Crassipes to thrive in dirty water as well as its propensity to accumulate heavy metal ions has drawn a lot of interest [11,12,13,14,15]. Plants absorb different metals based on their affinity for them. E. crassipes uses absorption and accumulation mechanisms to clear heavy metal and nutrient contamination from water bodies, sewage and sludge ponds. E. crassipes can remediate Pb, As, Hg, Zn, Se, Cr, Cd, Ni, and Cu in contaminated industrial and municipal streams [16,17,18,19,20,21,22,23,24].

The Scientific investigation presented in this paper involved the chemical preparation of copper nanocomposites using powdered water hyacinth (Eichhornia crassipes) root as fillers. The basis for the strong nature of the Copper-water Hyacinth Nanocomposite is due to the volume, surface aand quantum effects of the Nanoparticles. As nanoparticles are united chemically with other common material, the particles will help in grain refinement to a certain extent inducing an intragranular structure or intergranular structure formation which improves the grain boundary and advance the mechanical properties of materials.

The electrical conductivity, impact resistance, X-ray Diffraction, Nanocomposite size and morphology, functional groups and percentage moisture absorption were evaluated to study the appropriateness of the material for many applications, especially in water filter devices.

Copper nanoparticles, Cu (NP)s are shaped spherically with blackish-brown color. The particle sizes range from 30 to 70 nm of wide surface area that shows elevated sensitivity visible in the ultraviolet with high thermal and electrical conductivity, and antimicrobial activities affected by surface area and quantum effects [25]. Similarly, the surface area of different sized copper-based nanoparticles has a dramatic effect on electron affinity, energy levels, magnetic attributes, melting point, an affinity for polymer/biological/organic molecules, quantum effects, and catalytic distinctive features.

2. Methodology

2.1. Material preparation

2.1.1. Preparation of copper nanoparticles

The reagents used for the preparation of Cu (NPs) were copper (II) sulfate pentahydrate ($CuSO_4{\cdot}5H_2O$), ascorbic acid ($C_6H_8O_6$ or $HC_6H_7O_6$), and distilled water with the aid of laboratory glassware and a microwave oven. The Cu (NPs) were synthesized by chemical reduction and co-precipitation reaction methods described by the stoichiometric reaction as outlined in equation 1. The method was modified by Apea and Quansah [26] and adopted for use by Gyasi-Antwi [8,27]]for the preparation of copper-cellulose nanocomposite materials by preparing the copper nanoparticle in situ within the pore spaces of the cellulose material.

$$CuSO_4{\cdot}5H_2O\ (aq) + C_6H_8O_6\ (s) \rightarrow Cu\ (s) + C_6H_6O_6\ (aq) + H_2SO_4\ (aq) + 5H_2O(1)$$

Sixty grams (60 g) of $CuSO_4{\cdot}5H_2O$ crystals were dissolved in 150 mL of distilled water in a beaker whilst carefully mixing until the total dissolution of the crystals was attained. One hundred and forty-four grams (144 g) of ascorbic acid was dissolved in 360 mL of distilled water, and carefully poured into the solution of $CuSO_4{\cdot}5H_2O$, and stirred well to obtain a solution of Cu (NPs).

Nanomaterials possess bigger surface areas compared to similar masses of bulk materials. With the increase in surface area per mass of material, a larger amount of material interacts with the surrounding materials which affects reactivity. The advantages of a larger surface area and enhanced reactivity in nanostructured materials enable the creation of better catalysts and aid the nanoscale material surface operation for applications that span from drug delivery to more economical ways of production and storage of energy.

2.1.2. Preparation of copper nanocomposite

The solution of Copper Nanoparticles was added to the dried Water Hyacinth powder in a reaction vessel, stirred meticulously, and allowed to stand for 24 h. The water Hyacinth act as a host for the copper nanoparticles which occupy the interstitial sites to form the nanocomposite. The Cu(NPs)-water Hyacinth mixture was sieved, and the filtrate dried in a microwave oven for 15 min, followed by air drying. After 24 h of air drying, the copper nanoparticle-water hyacinth mixture was washed thoroughly with distilled water to eliminate any excess Cu (NPs). The mixture was dried in a microwave oven at 100 °C at 1-hour intervals until the sample reached constant mass and the moisture content evaluated on a dry basis.

2.1.3. Molding of the copper nanocomposite slab

Polyvinyl formal ($C_5H_8O_2$) and Calcium carbonate ($CaCO_3$) wood adhesive (Top Bond Glue), an electrically insulating glue, was mixed with water and blended thoroughly with the Cu (NPs)-water hyacinth mixtures in the ratio of 1:1, to form a uniform paste. The pastes of Cu (NPs) water hyacinth powder adhesive composite was molded by cold-pressing in rectangular molding boxes measuring 55 mm × 10 mm × 10 mm, using a wooden compactor. The nanocomposite was preserved by drying for 24 h, taken away from the mounds and dried in air for 48 h. A sample of the nanocomposite in the shape of a rectangular slab is shown in Fig. 1.

The copper–water hyacinth nanocomposite was dark-green, and the shrinkage on removal from the mounds and drying to an equilibrium moisture content of 10 % was minimal, affirming the suitability of the applied compaction pressure.

2.2. Analytical methods

2.2.1. Fourier-Transform Infrared (FTIR) spectroscopic characterization of Cu (NP)-water hyacinth composite

The molecular functional groups of Cu (NP)- Water hyacinth composite was ascertained by Fourier-Transform Infrared (FTIR) vibrational spectroscopy [28], in the frequency range 4000– 415 cm^{-1}. The broadband at frequencies listed in Table 1 is an illustration of the FTIR spectrum in Fig. 2.

Table 1 shows the band number and the corresponding frequency

Fig. 1. Represents a slab of Copper-Water Hyacinth Nanocomposite.

Table 1
Broadband Frequency of FTIR.

Band Number	Frequency/cm
1	3695.66
2	3321.05
3	2926.04
4	2853.09
5	1627.48
6	1514.77
7	1424.75
8	1361.31
9	1317.69
10	1234.89
11	1028.12
12	912.08
13	819.68
14	796.99
15	532.57
16	501.20
17	466.43
18	417.23

The FTIR spectrum broadband of 3321.05 cm^{-1} was due to O-H stretching vibration on the surfaces of Copper Nanocomposite. Water hyacinth consists of crude protein, amino acid, minerals and vitamins and the FTIR medium indicated signals band at about 2926.04 cm^{-1}, which characterized symmetric and asymmetric vibrations of-CH-(Alkane groups). The bands close to 1627 cm^{-1} are associated with stretching of C = C bonds of Alkene or Aromatic groups with bands in 1424 associated with C-H deformation asymmetry. The band at 1028 also depicts the C-O stretch.

The strong absorptions at 819.68 cm^{-1} and 796.99 cm^{-1} are attributed to the out-of-plane bending vibration of aromatic C-H. The bands at 532.57 cm^{-1}, 466.43, 417.23 cm^{-1} are mainly due to C-X (haloalkanes) [29,30].

Some functional groups of macromolecular constituents of water Hyacinth (crude protein, amino acid, minerals, and vitamins), with major chemical constituent oxygen and carbon, were identified in the infrared spectrum.

2.2.2. Impact testing

Standard Charpy impact test was used to ascertain the toughness of Cu (NP)-Water hyacinth composite by exposing it to impact loading and multi-axial stress states. Tinius Olsen High Energy Pendulum Impact Testing Machine, Model IT 406, was tested and adjusted to the highest accuracy, observing the Manufacturer's function procedures. The pendulum was raised into starting position, the tester checks were performed for accurate adjustment of the machine, and the drag indicator moved downwards for the pendulum to be released without a test specimen, whereby the drag indicator ceased movement at position zero. The process established that the pendulum had been set at the correct starting position and that any errors from friction had been correctly accounted for.

The swinging pendulum was used to assess a notched bar of the composite with the pendulum heights before and after impact, to compute the energy required to break the bar apart [31]. Charpy impact test was also carried out by holding the composite horizontally amid two vertical bars. The hammer was used to break the Nanocomposite, dropping at a predetermined velocity through a fixed distance.

The energy absorbed in demolishing the composite in a single impact blow was evaluated for the Charpy impact test of the V-Notch specimen. The impact energy was determined using the formula,

$$Impact\ energy = mgH - mgh \quad (2)$$

where m was the mass of the composite, H was early pendulum height, h was height attained by pendulum after the impact, and g was the value of acceleration due to gravity.

2.2.3. Electrical conductivity measurement

Simple direct current Ohm's bridge of ammeter-voltmeter connections was used to evaluate the electrical conductivity, resistivity, and field strength of Cu (NP)-water Hyacinth composite in rectangular-shaped slabs. A voltage source, variable resistor, and digital ammeter in a series connection with the nanocomposite (specimen) via metal clip probes formed the circuit, while a digital voltmeter was connected in parallel across the composite. The source voltages were changed from 4.0, 6.0, 8.0, 10.0 to 12.0 V, and the equivalent ammeter readings (I) and voltmeter readings (V) were recorded. The data was used to evaluate the electrical conductivity, resistivity, and electric field strength.

From the specimen dimensions, the cross-sectional area A was calculated, and the conductivity, $\sigma = LI/VA$, was determined, where V was the voltage across and I was current through the rectangular slab of length L. The electrical resistivity or inverse of conductivity, $\rho = 1/\sigma$, was also evaluated. The potential gradient, V/L determined is the

Fig. 2. FTIR Spectrum for Copper-Water Hyacinth Nanocomposite.

electric field intensity.

2.2.3.1. Moisture content-voltage relationship. The influence of moisture on values of electrical conductivity was examined. The composites were immersed in water for absorption in 10 min, and V and I measured after drying. Plots of potential difference across the nanocomposite against percentage moisture content (on a dry basis) were closely examined to confirm the relationship.

2.2.4. Transmission Electron Microscopy (TEM)

TEM uses an electron beam created by a hot tungsten filament located at the top of an evacuated column. The beam is fast-tracked down the column by a high voltage source from 100 to 300 kV. The electron beam condensed by Electromagnetic coils is made to pass through the thin specimen located on the specimen stage. Some of the electrons passing through the specimen are absorbed while some are scattered so that they change direction. After the electron beam has moved through the specimen it is fixated with the objective coil (magnetic lens) and then magnified and stuck out on a fluorescent screen. An image is created by bringing together either the direct electrons or the scattered electrons.

The Copper-Water Hyacinth Nanocomposite sample was ultrasonicated for ten minutes in Ethanol Hydroxide and prepared on a 3 mm Carbon-coated Copper grid for TEM analysis. From the TEM, the size and electron diffraction measurements of the Nanocomposite were determined.

Fig. 3 shows the various spherically shaped sizes (small and large particles) of the Nanocomposite. The smaller particles (about 39) have a size of 2.6 ± 0.4 nm whilst the large particles ranged from 3 to 10 nm. The average size of the Nanocomposites (87 in number) was 5.5 ± 1.7 nm. Fig. 4 represents Eletron Energy Loss Spectroscopy. EELS, Fig. 5 a line scan by EELS and EDS and Fig. 6 Bragg Peaks.

The Copper 111 200 and 220 rings were visible in the electron Diffraction experiment. Electron Diffraction Studies show reflexes corresponding to lattice values of 2.06 Å, 1.80 Å, and 1.27 Å that can be attributed to the copper ((111), (200), and (220) planes respectively.

2.2.5. X-ray diffraction

A powdered sample of the Copper-Water Hyacinth Nanocomposite was subjected to X-ray Diffraction analysis so that there will be an arbitrary orientation of several crystals to ensure that some of the particles will be aligned in the X-ray beam to fulfill Bragg's law of diffraction conditions.

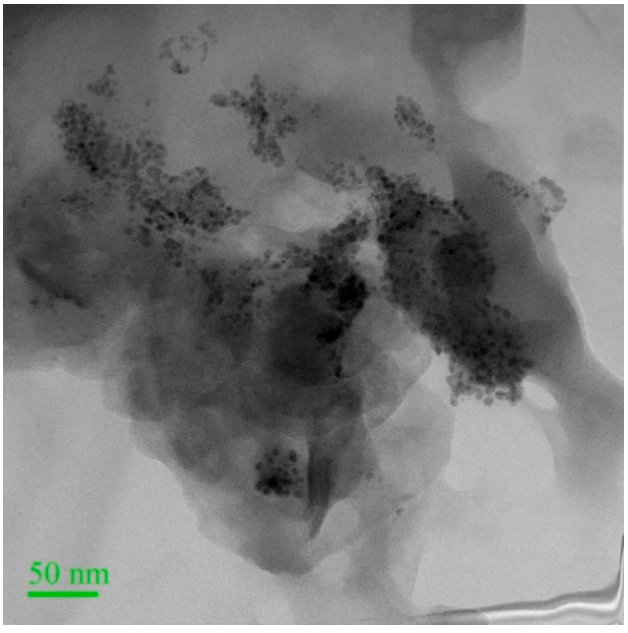

Fig. 3. Shows another cluster of the Copper-Water Hyacinth Nanocomposite.

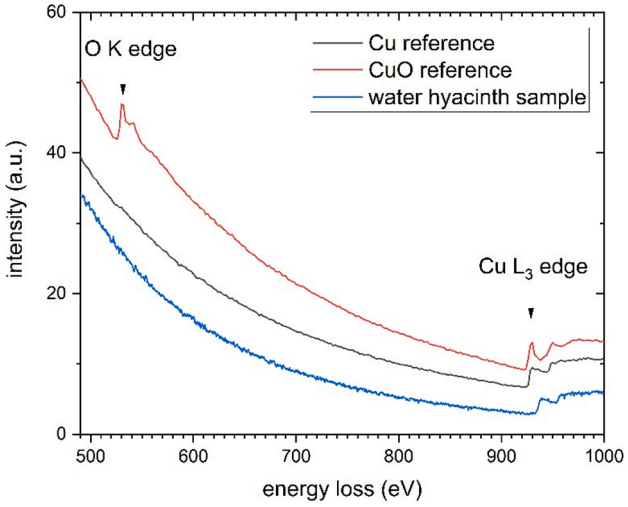

Fig. 4. Electron Energy Loss Spectroscopy (EELS) reference spectra of copper samples (from EELS Atlas/Gatan) [32] shows copper L edge onset at 925 eV and Oxygen edge at 530 eV.

The lattice parameter, lattice structure, and indices of the diffracting planes were evaluated by Bragg's law [33],

$$n\lambda = 2d_{hkl}.sin\theta$$

where n is the order of reflection of the integer (1, 2, 3,.) in agreement with sinθ not exceeding unity, 2θ is diffraction angle, d_{hkl} is interplanar spacing (h, k, and l are Miller indices) and λ is the wavelength of X-rays.

The results are presented in Tables 2 and 3 above. The Miller indices for the angles 21.7°, 25.3° and 45° are (111), (200), (311) with corresponding Crystallite sizes as 14.7 nm 15.1 nm, and 19.3 nm; interatomic spacing as 2.1 Å,1.8 Å and 1.1 Å and lattice constant being 3.60 Å, 3.61 Å and 3.61 Å respectively. This value compares well with the bulk lattice constant value of copper (3.597 Å).

3. Results

3.1. FTIR characteristics

The band 3321.05 cm^{-1} affirmed the presence of O-H (Hydroxyl) stretching vibration on the surfaces of Copper Nanocomposite whilst the signals band at about 2926.04 cm^{-1}, characterized symmetric and asymmetric vibrations of-CH- (Alkane groups). The bands close to 1627 cm^{-1} are associated with stretching of C = C bonds of Alkene or Aromatic groups with bands in 1424 cm^{-1} associated with C-H deformation asymmetry. The band at 1028 cm^{-1} also depicts the C-O stretch.

The strong absorptions at 819.68 cm^{-1} and 796.99 cm^{-1} are attributed to the out-of-plane bending vibration of aromatic C-H. Some functional groups of macromolecular constituents of water Hyacinth (crude protein, amino acid, minerals and vitamins) were detected in the infrared spectrum.

3.2. Charpy test results

The energy of fracture for Copper-Eichhornia Crassipes (Cu-WH) nanocomposite was 27.98 J. The impact strength data of the Cu (NP)-water Hyacinth composite compared with other Nanocomposites is represented in a bar chart shown in Fig. 7. The percentage impact hardness of the Copper-Water Hyacinth nanocomposite is 20.89% compared to the Copper-Sawdust (20.08%), Copper-Maize Testa

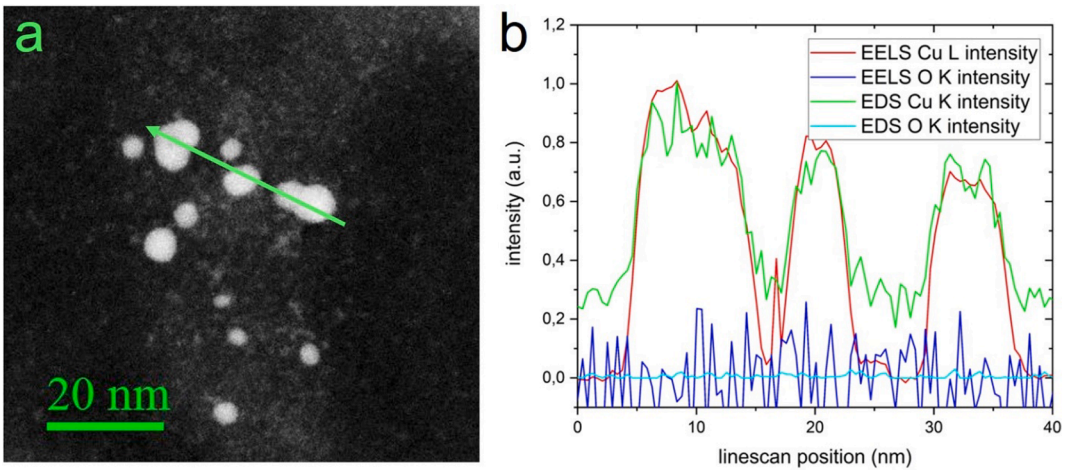

Fig. 5. Line scan analysis by EELS and Energy Dispersive Spectroscopy (EDS), respectively. A) HAADF STEM image of copper nanoparticles with indicated line scan b) EELS and EDS signal intensity of Cu and O, respectively, recorded along the line in a) simultaneously. There is no oxygen detectable in the particles. The non-vanishing copper signal in the EDS line scans (green line) in between the particles is due to stray radiation. This is an artifact of the EDS measurement and absents in the EELS (red line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

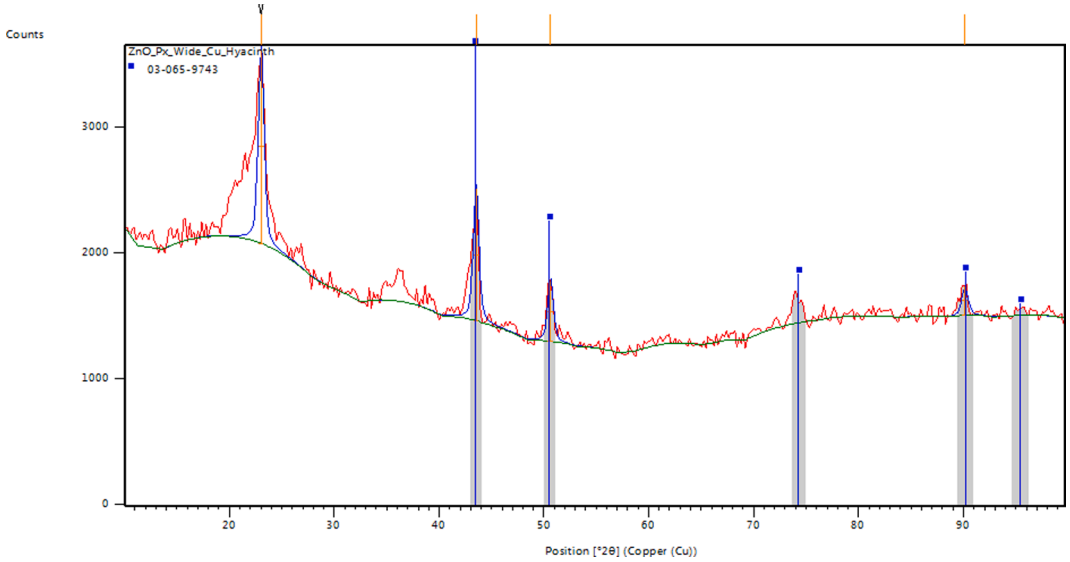

Fig. 6. Shows Copper-Water Hyacinth Nanocomposite peaks from the X-Ray diffraction experiment.

(20.7%), and Copper-Ginger nanocomposites (38.33%).

The Charpy Impact test of the Copper-water hyacinth can be compared to other work by [34] in Fig. 8. The impact energy in Fig. 7 compares very well with reinforcement with 5.5 steel nanoparticles in Fig. 8. The metal fillers in Fig. 8 enable higher impact strength than the Nanocomposite in Fig. 7.

Nanomaterials possess excellent mechanical properties owing to the volume, surface and quantum effects of the Nanoparticles. As nanoparticles are combined with other common material, the particles will aid in grain refinement to a certain extent leading to the formation of an intragranular structure or intergranular structure which improves the grain boundary and advance the mechanical properties of materials [35,36]. This is the basis for the robust nature of the Copper-water Hyacinth Nanocomposite.

3.3. The sources of resistance

Metals can be recognized as a lattice of positively charged metal ions surrounded by a 'sea' of mobile electrons that are delocalized in the metal's conduction band. A net movement of electrons in the metal's conduction band occurs when a potential difference is applied to the metal in a circuit. The movement of electrons is restricted by the vibration of the atoms in the metal lattice, which causes part of the electrical energy of the electric current to be lost, resulting in resistance. The resistance of metals increases as the temperature rises since lattice vibrations increase as the temperature increases. Electrical conductors, such as metals possess low resistances. A perfect conductor would have zero resistance. Electrical insulators have very high resistances. An ideal insulator would have infinite resistance: since no current could flow through, it would not dissipate any energy.

The Copper nanoparticles which are metal behave as a conductor whilst the water Hyacinth made up of cellulose materials behaves as an insulator. The copper–water hyacinth Nanocomposite, therefore, exhibits the two characteristics resulting in a semiconductor behavior.

3.4. Voltage – current relationship

A plot of the voltage-current relationship for the nanocomposite is shown in Fig. 9. The electrical conductivity, electrical resistivity, and electric field strength values obtained from the data were

Table 2
X-ray Diffraction Results presented in Tables 2 and 3.

2Theta	Theta	Sinθ	$(Sinθ)^2$	$((Sinθ)^2/0.0458))$	Miller indices
43.4986	21.7493	0.3705	0.1373	3	111
50.5959	25.29795	0.4273	0.1826	4	200
90.066	45.033	0.7075	0.5006	11	311

Table 2 shows the evaluation of the Miller Indices.

Table 3
Shows the crystallite size, interatomic spacing, and the lattice constant.

FWHM	β	Crystallite Size/nm	$\sqrt{h^2+k^2+l^2}$	Interatomic Spacing d/Å	a/ Å
0.5815	0.0102	14.7029	1.7321	2.08054	3.6036
0.5815	0.0102	15.1048	2.0000	1.80410	3.6082
0.5815	0.0102	19.3239	3.3166	1.08964	3.6139

$(3.64 \pm 0.02)x10^{-2}(\Omega m)^{-1}$, $27.504 \pm 0.02\Omega m$, $224.165 \pm 0.02Vm^{-1}$.

3.5. Variation of voltage with percentage of moisture

The increase in Voltage resulted in a corresponding increase in moisture content in a linear graph as shown in the variation of voltage with the percentage of moisture content in Fig. 10.

3.6. Transmission Electron Microscopy (TEM)

The small-sized Nanocomposite particle was 2.6 ± 0.4 nm with the larger size in the range of 3–10 nm. The average particle size was 5.5 ± 1.7 nm. All the particles were spherically shaped.

Electron Diffraction studies confirmed the presence of signals corresponding to (1 1 1), (2 0 0) and (2 2 0) planes of copper. Electron Energy Loss Spectroscopy (EELS) confirms the presence of elemental copper.

The Energy Dispersive X-ray Spectroscopy (EDS) confirmed the presence of copper metal in the nanocomposite.

3.7. X-ray diffraction

For the angles, 21.7°, 25.3° and 45°, the Miller indices are (1 1 1), (2 0 0), (3 1 1) with corresponding Crystallite sizes as 14.7 nm 15.1 nm, and 19.3 nm; interatomic spacing as 2.1 Å,1.8 Å and 1.1 Å and lattice constant being 3.60 Å, 3.61 Å and 3.61 Å accordingly. The lattice constant was very close to the lattice constant of bulk copper (3.597 Å).

4. Discussion

The preparation of extremely practical, novel metal-cellulose nanocomposites from cheap natural fibers for commercial reasons with a short turnaround time has been successfully carried out. The larger surface area of the nanomaterial enhances the reactivity and surface activity.

The Copper -Eichhornia Crassipes nanocomposite had an electrical conductivity of $(3.64 \pm 0.02)x10^{-2}(\Omega m)^{-1}$, the electrical resistivity of $27.504 \pm 0.02\Omega m$, the electric field strength of $224.165 \pm 0.02Vm^{-1}$, 010 V/% moisture content and mechanical impact energy of 27.98 ± 0.02 obtained from the data, accordingly. The conductivity value of the copper nanocomposite material is in the semiconductor range. The Copper Nanoparticle which is a metal behaves like a conductor and the water Hyacinth, a cellulose material is an insulator. The combined characteristic behavior resulted in the semiconductor property. Also, the volume, surface and quantum effects of the Nanoparticles provide excellent impact energy. Moreover, the composite nature of the nanocomposite material accounts for the particles, aiding in grain refinement to a certain extent, leading to the formation of an intragranular structure

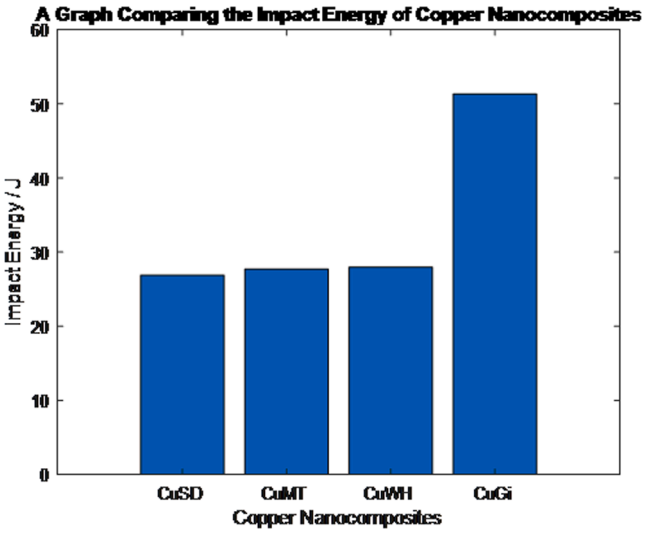

Fig. 7. Bar Chart comparing Copper-Water Hyacinth Nanocomposite with other Nanocomposites *Cu-SD = Copper-Sawdust Nanocomposite, Cu-MT = Copper- Maize Testa Nanocomposite, Copper-Water Hyacinth Nanocomposite and Copper-Ginger Nanocomposite.*

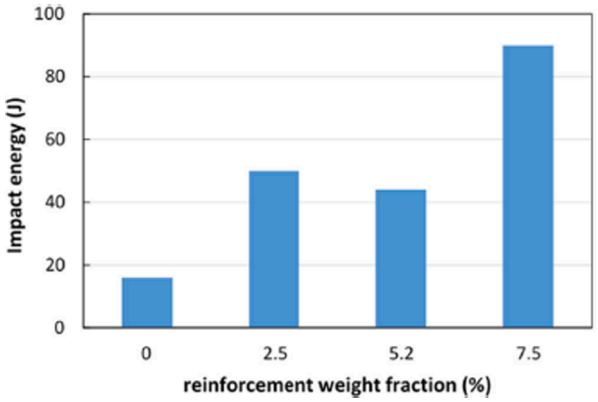

Fig. 8. The Charpy impact energy of pure copper and copper composites reinforced by 2.5, 5.5, and 7.5 wt% steel nano-particles [34]

or intergranular structure which improves the grain boundary and advance the mechanical properties of materials [35,36].

The O-H stretching vibration on the surfaces of Copper Nanocomposite, the symmetric and asymmetric vibrations of-CH- (Alkane groups), the stretching of C = C bonds of Alkene or Aromatic groups, the C-O stretch, the out-of-plane bending vibration of aromatic C-H and macromolecular constituents of water Hyacinth (crude protein, amino acid, minerals and vitamins) are some of the functional groups identified by the FTIR Spectrum.

The conductivity value showed the nanocomposite could be designated as an intrinsic semiconductor [37,38], but no further examinations were made to critically observe the change to extrinsic semiconductor state or evaluate the majority and minority carriers, bandgap and other parameters of semiconductors used in the electronic industry.

The surface features or morphologies, particle sizes and crystal structure were adequately evaluated in the research. The X-ray Diffraction studies provided information on the crystal nature of the Copper Nanocomposite.

The research adequately addresses detailed studies of the Copper-Water Hyacinth at the Nanoscale.

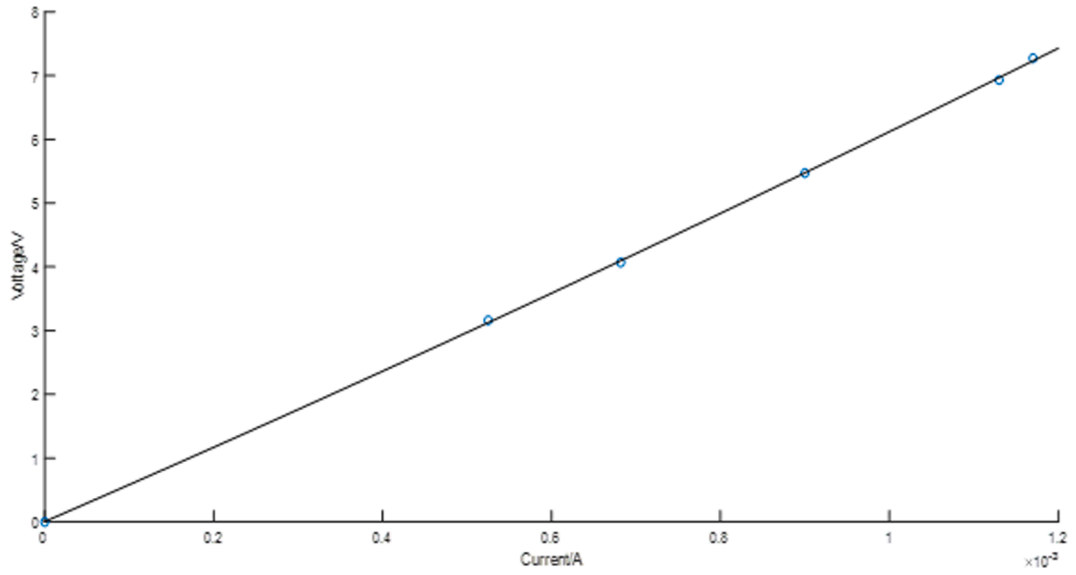

Fig. 9. Shows a Graph of Voltage against Current for the Copper Nanocomposite.

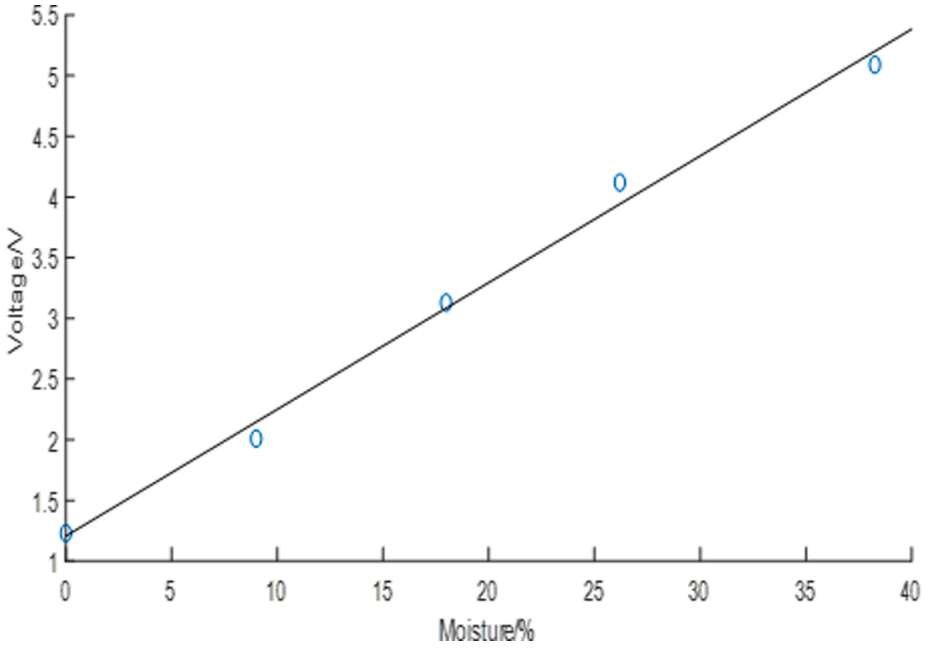

Fig. 10. Shows a Graph of Voltage against % Moisture content for the Copper Nanocomposite.

5. Conclusion

The Chemical Reduction method remains one of the popular techniques to synthesize novel Nanocomposites because it is easier, economical, and shorter turnaround time compared to other methods. Copper-Water Hyacinth nanocomposite was produced and Electrical, mechanical, Infrared Spectroscopy, Microscopic and X-ray diffraction properties were determined. The electrical conductivity table determined the Nanocomposite to be a Semiconductor. The voltage also increased with an increase in percentage moisture content. The Impact energy value compared very well with all the other Nanocomposite materials (Copper-Maize Testa, Copper-Water Hyacinth, Copper-Ginger); Generally, a summary of the properties indicates that the Copper-Water Hyacinth Nanocomposite can become a potential material in Water filter devices.

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Credit authorship contribution statement

Conceptualization, investigation, and formal analysis were performed by **Gyasi-Antwi** and **Aladin Ullrich** under the supervision of **Ohene Boansi Apea** and **Dodoo-Arhin**. **Gyasi-Antwi** prepared the manuscript with contributions from all the co-authors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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