Investigation and analysis of a sustainable agro-based nanocoating on surface of metallic materials

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Abstract. In this study, nanotechnology was used to develop a coating from agricultural waste. Banana peels underwent various chemical processes, nanoparticles were developed and tests were conducted to validate it. The metal samples used for coating application were made of mild steel which is used to produce a large percentage of metal parts in the industry and was selected for this research project due to that reason. The metals were cut into 50 mm x 50 mm and 50 mm x 30 mm. The sample coatings included a control coating which was used as the yardstick to know the effects of the nano coating applied which contained various concentrations of nanoparticles showed results that were more favorable than the coatings that were applied without nanoparticles contained in them. Qualitative analysis of the coated metal samples A to G showed that sample E which had 7.24 grams of nanoparticles contained in it had the highest amount of hardness while sample A which was control coating possessed the least hardness amount. The abrasion test of the samples revealed that sample D which had 21.72 grams of nanoparticles contained in it possessed the highest weight of coating before and after the abrasion test

1 Introduction

Coating is the most popular method for protecting materials from corrosion. It can be applied at various temperature ranges which also helps in enhancing the efficiency of the flow on material surfaces [1]. There are many techniques to achieve the molecular/atomistic deposition on a substrate: chemical vapor deposition (CVD), physical vapor deposition

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(PVD), electro-less plating, electroplating, plasma-enhanced CVD, laser vaporization and others [2]. Physical vapor deposition (PVD) is generally used in coatings and thin film fabrication. Industrially, physical vapor deposition has been combined with other various methods of producing coating which possess higher properties [3-4]. Agricultural wastes like rice husk, black ash and palm fiber recycle has become a major resource for poverty alleviation since after the Second World War ended in 1945 [5-7]. Agricultural waste has been used as raw materials in producing alternative building products. In a recent study, investigation was carried out on the effects of agro-wastes such as wheat straw ashes, sugarcane bagasse and rice straw in clay bricks. Previously, agro wastes have been found to be viable sources of biogas [8-9], however with advancement in technology, the possibility of the application of agro-wastes for other innovative purposes is being studied. The use of agro waste as a possible replacement for other materials especially in engineering has recently spiked with various attempts by researchers to find viable uses for these agro wastes. Wastes that have been put to such use include wheat straw used as a building material, diluted apple waste extract was also put into good use [10-12]. Although advancement in technology could be viewed as a merit, one of the demerits it poses is the sharp increase in pollution. There is therefore a need for the development of materials that could reduce pollution, thereby solving a major environmental problem [13]. Nanoparticles are gaining huge scientific interests due to their significant effect on interfacial mass transfer which has many applications in industrial processes; in particular, the application of nanotechnology in agriculture could aid an increase in the rate of production and as well minimize waste [14-15].

2 Materials and Methods

2.1 Materials

The main materials used for the study were Banana peels, Distilled water, Mild steel plates and ferrous chloride. The banana peels were obtained from a dump site and dried under sunlight to eliminate the amount of moisture in it. Later, the peels were burnt to form fine powder, Figure 1a. For the nanoparticle synthesis, distilled water was used to confirm the mixtures were impurity free in order to get appropriate results, Figure 1b. The metal samples used for coating application were made of mild steel which is used to produce a large percentage of metal parts in the industry and was selected for this research project due to that reason, Figure 1c. Ferrous Chloride was needed in the experiment for the synthetization process.

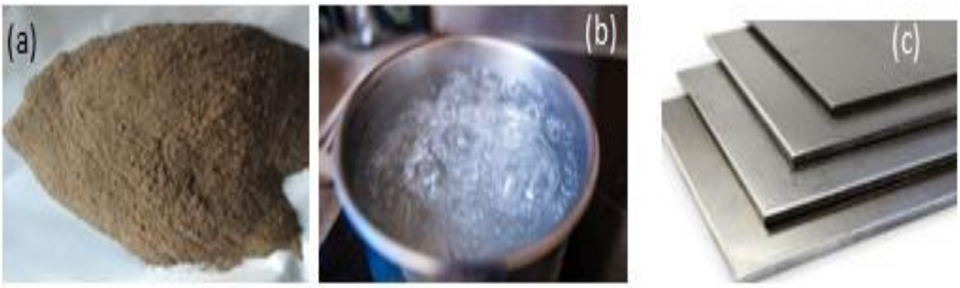

Fig. 1. Materials used for study (a) Banana peel in powder form (b) Distilled water (c) Mild Steel Plates

2.2 Equipment

The major equipment employed for the study includes a beaker, spatula, measuring scale, magnetic stirrer, measuring cylinder, centrifuge tubes, centrifuge machine and a disc cutter. The beaker was used in the synthesis of the nanoparticles. The size of the beaker used in the process was 1000 milliliters, Figure 2a. The spatula was used for mixing solutions and scooping out residues and other materials in the process. The spatula is shaped like a spoon. A measuring scale was used to measure the banana peel powder and iron chloride to accurate quantities needed for the synthesis process. A magnetic stirrer of volume 2000ml was used to stir the mixtures during the synthesis process, Figure 2b. Distilled water was measured using the measuring cylinder of volume 1000ml, Figure 2c. Centrifuge tubes were used in separating the nanoparticles from the fluids. They were placed in the centrifuge machine to undergo the separation process. The motor of a centrifuge machine rotates high speed which is applied in the separation process. It separates solids and liquids with solids resting below the liquid at the bottom of the centrifuge tube. A disc cutter was used to cut the metal samples into 50 mm x 50 mm and 50 mm x 30 mm because of the type of tests to be carried out on them.

Fig. 2. Equipments used for study (a) Centrifuge tubes (120cc) (b) Magnetic stirrer (c) Measuring cylinder

2.3 Methods

2.3.1 Ash preparation

The banana peels were obtained from a dump site and dried under sunlight to eliminate the amount of moisture in it. Later, the peels were burnt to form fine powder, Figure 3a.

2.3.2 Synthetization

In the synthetization process, 0.1 moles of ferrous chloride solution and banana peel powder in a volume ratio of 2:1 were mixed together. The mixture was stirred with a magnetic stirrer for some time and was kept at room temperature for 60 minutes. The change in color of the solution from brown to black was observed and recorded.

2.3.3 Centrifugal process

After a couple of days, the mixtures were poured into centrifuge tubes. The centrifuge tubes were placed in the centrifuge machine which was set at 8000 revolutions per minutes for each set. At the bottom of the centrifuge tubes is where the nanoparticles settled, Figure 3c.

2.3.4 Calcination

The nanoparticles were removed from the tubes and placed in crucibles for the calcination process. The calcination process took place by placing the crucibles filled with the nanoparticles in a furnace and heating it up with high heat intensity in order for any available moisture to dry up, Figure 3d.

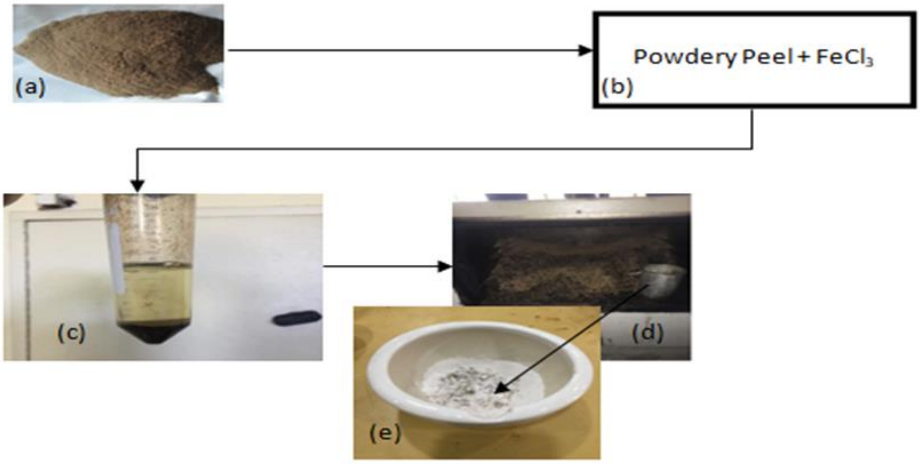

Fig. 3. Methods adopted during study (a) Ash preparation (b) Synthetization (c) Centrifugal process (d) Calcination process (e) Crucible used during calcination process

2.3.5 Metal sample preparation

The metal samples used for the coating process were cut into the desired shape and size. The metal samples are made of mild steel and a disc cutter was used to cut the metals into 50 mm x 50 mm and 50 mm x 30 mm because of the type of tests to be carried out on them. A surface grinding machine was used to polish the metal samples and give them a better surface finish.

2.3.6 Application of surface coating

The metal sheet samples used for the study were labeled based on study conditions, *Figure 4*. Surface coatings consisting of resins, hardeners, additives with various concentrations of nanoparticles were applied to the metal samples. A control coating was applied to a metal sample. Metal Sample A was applied with a control coating on the surface. Metal Sample B was applied with a concentration of resin, hardener and additives with no concentration of nanoparticle added to it. Metal Sample C was applied with a concentration of resin, hardener and additives with 18.1 grams of nanoparticles added to it. Metal Sample D was applied with a concentration of resin, hardener and additives with 21.72 grams of nanoparticles added to it. Metal Sample E was applied with a concentration of resin, hardener and additives with 7.24 grams of nanoparticles added to it. Metal Sample F was applied with a concentration of resin, hardener and additives with 14.48 grams of nanoparticles added to it. Metal Sample G was applied with a concentration of resin, hardener and additives with 10.86 grams of nanoparticles added to it.

Fig. 4. Metal samples used for the study labeled based on various applicable conditions.

3 Results and Discussions

3.1 Characterization of nanoparticles

The nanoparticles (iron nanoparticles) and the banana peel powder underwent characterization so that its composition would be determined. Various tests such as Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and Energy Dispersive Spectroscopy (EDS) were carried out on the banana peel powder and the iron nanoparticles to determine its characteristics.

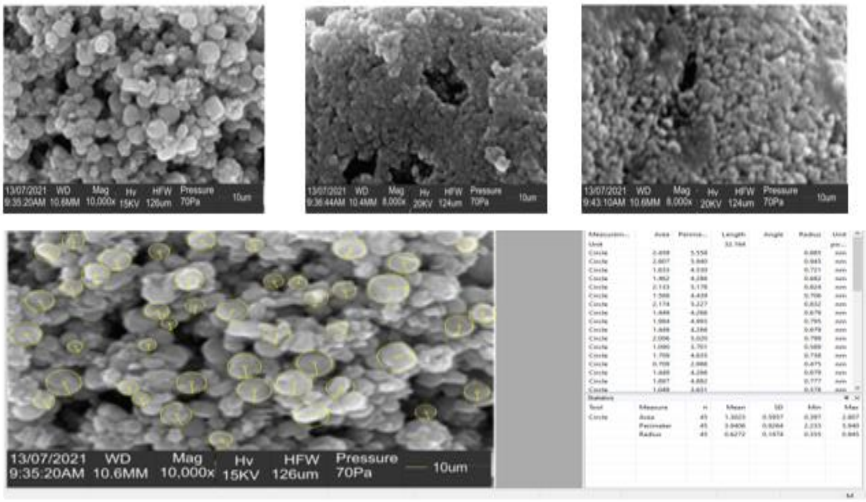

Fig. 5. Digimizer image for SEM image (Iron nanoparticles)

The particle size of the iron nanoparticles is shown having a mean area of 1.3025 nm^2, mean perimeter of 3.9406 $nm^2$and a length of 0.3934 nm. Various magnifications of particle size are shown in the image above. The Digimizer^{TM}image analysis software was used to analyze the SEM micrograph, *Figure 5*.

3.2 Energy Dispersive Spectroscopy (EDS) analysis

Elements present in the banana peel and iron nanoparticles were determined by the Energy Dispersive Spectrometer. Comparing both figures, high peaks of oxygen can be noticed with 23.3% from the banana peel and 20.02% from the iron nanoparticles, *Figure 6a&b*. High peaks of Iron is also noticed with 57.10% from banana peel and 77.85% from iron nanoparticles, *Figures 6a&b*. Carbon is also present in 7.30% from banana peel and 3.22% from iron nanoparticles, *Figure 6a&b*.

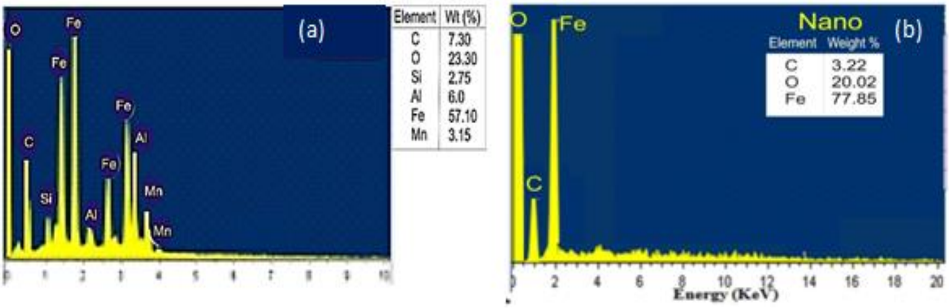

Fig. 6. EDS graphs of nanoparticles (a) banana peel (b) iron

3.3 Qualitative analysis of coating

The results of the hardness test performed on sample A to sample G shows that from the three columns of values, sample E possesses the highest amount of hardness while sample A which was used as a control possesses the least amount of hardness, *Table 1*. This could be because sample A contained no amount of nanoparticles in it. From the table, it can be seen that HV 100 generally had the highest values compared to HV 30 and HV 3. Hence, the presence of nanoparticles in the base mixture was a catalyst to an increased hardness value which made the coatings more preferable.

Table 1. Hardness Test on Coatings

Samples	HV 3	HV 30	HV 100
Sample A	5.8	16.4	15.6
Sample B	8.4	17.0	18.5
Sample C	9.2	14.5	19.4
Sample D	6.3	12.7	16.4
Sample E	9.5	18.4	22.2
Sample F	7.1	16.0	17.6
Sample G	8.2	13.5	16.5

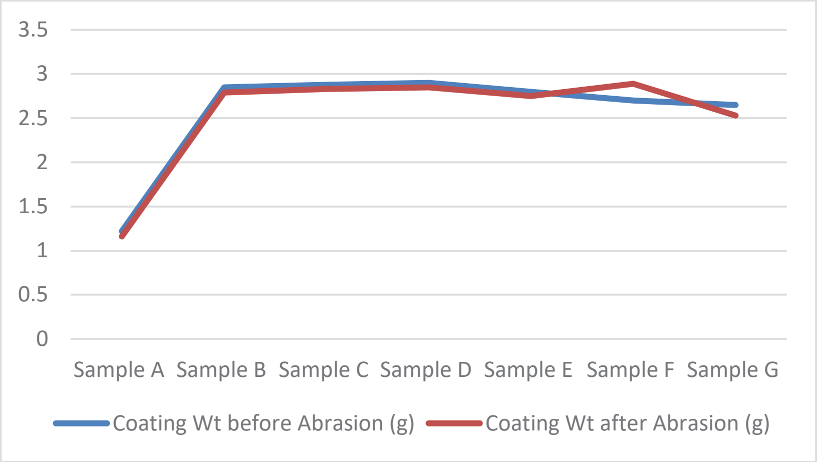

Fig. 7. Graph of Samples against Coating weight before abrasion and after abrasion.

Table 2. Abrasion test of material samples

Samples	**Coating Wt before Abrasion (g)**	**Coating Wt after Abrasion (g)**	**Mean Value of Abrasion (g)**	**Loss of Wt (%)**	**Abrasion Resistance (%)**
Sample A	1.22	1.16	0.06	4.91	95.08
Sample B	2.85	2.79	0.06	2.11	97.89
Sample C	2.88	2.83	0.05	1.74	98.26
Sample D	2.90	2.85	0.05	0.02	98.28
Sample E	2.80	2.75	0.05	1.79	98.21
Sample F	2.70	2.89	0.06	2.05	97.55
Sample G	2.65	2.53	0.05	2.74	96.26

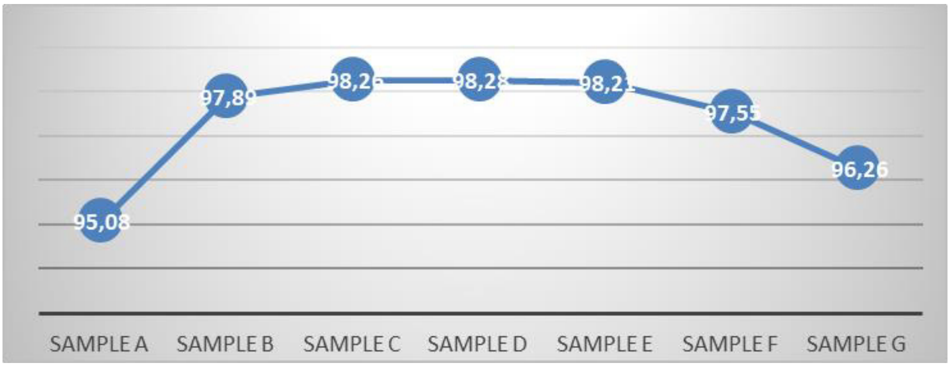

Fig. 8. Graph of Samples against Abrasion resistance

Martindale abrasion tester is used in determining the abrasion resistance of various types of structures. The first column of values indicates the weight of the coating after the abrasion test which notably decreased, *Table 2*. The third column of value indicates the mean value of abrasion which was found by subtracting the weight of the coating after the abrasion test from the weight of the coating before the abrasion test. The fourth column of values indicate the percentage loss of the weight of the coating which was obtained by dividing the mean values of abrasion by the weight of the coating before the abrasion test and multiplying it by 100%. The last column which indicates the percentage abrasion resistance was obtained by subtracting the percentage loss from 100. From the table, sample D possesses the highest weight of coating before and after the abrasion test. Sample A has the least percentage of abrasion resistance. Sample D contains the highest grams of nanoparticles (21.72 grams) out of all the samples tested. The presence of nanoparticles in sample D contributed to the high percentage of abrasion resistance. The values of the coating weight before and after abrasion slightly differ, *Figure 7*. The values of the abrasion resistance from Sample A to Sample G almost form a bathroom curve in the graph, *Figure 8*. The values rise along the graph and return to a diminishing state.

Table 3. Adhesion and Flexibility Test on Coatings

Samples	**Flexibility Test (g)**	**Adhesion Test (g)**
Sample A	2.24	5.16
Sample B	2.25	5.19
Sample C	2.28	5.13
Sample D	2.20	5.25
Sample E	2.20	5.05
Sample F	2.22	5.55
Sample G	2.28	5.43

Flexibility and adhesion test was performed on the various samples. Adhesion test on coatings is necessary to understand how well the bond between the applied coating and the substrate is. If the applied coating is not adherent, it can cause issues with operation. Flexibility test on coating is necessary to determine the rate at which the applied coating is resistant to cracking. The second column from the table above shows the values of the flexibility test of sample A to sample G. Sample C and sample G were found to have the highest value of 2.28 for the flexibility test while sample D and sample E had the least value of 2.20. For the third column which contains the values obtained from the adhesion test, sample F was found to have the highest value of 5.55 for the adhesion test while sample E was found to have the least value of 5.05 for adhesion test, *Table 3*. This is most likely as a result of the amount of nanoparticles varied in both samples which determine its adhesion rate.

3.4 Micro-structural analysis for coating

The metal samples were tested to validate the effectiveness of the surface coatings applied on them. Tests that were carried out include abrasion test, adhesion test, flexibility test and hardness test. Tests were carried out on metal sample A which is the control coating. The particles seem to possess some high level of porosity, high abrasion resistance and low level of hardness, *Figure 9*. They have a smooth texture and a microstructural non-uniform arrangement. The particles in shows that it possesses a high abrasion resistance, low flexibility, low level of adhesion and a high level of hardness, *Figure 9b*. The particles shows that it possesses a high amount of hardness, high abrasion resistance and very low adhesion rate due to the high amount of nanoparticles contained in it, *Figure 9c*.

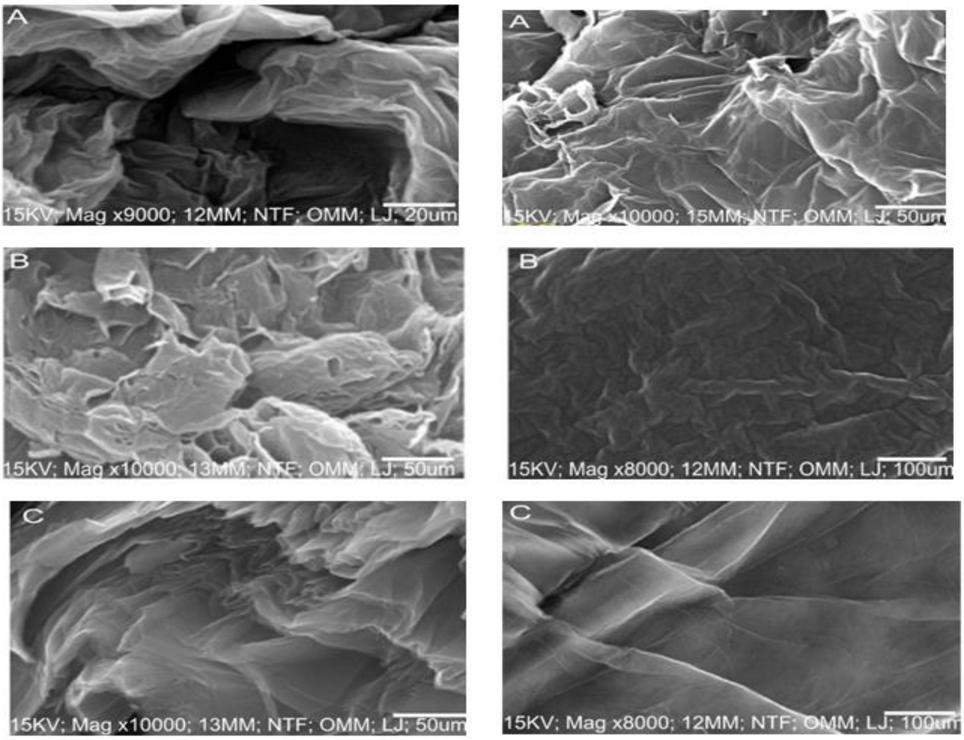

Fig. 9. Microstructural images of metal samples (a) control coating (b) consisting of a concentration of resin, hardener and additives with no concentration of nanoparticle added to it (c) applied with a concentration of resin, hardener and additives with 18.1 grams of nanoparticles added to it.

4 Conclusion

From the results and discussion, banana peel was used to develop iron nanoparticles which were subsequently used to develop nano coating. The analysis of the applied coating on the various samples was studied. This is a summary of the results

- The size of the nanoparticle was revealed via scanning electron microscopy. The size of the particles ranges from a value of 3.9406nm^{2}to 5.840nm^2, a mean or average size of 1.3025nm^2 which verifies that it lies in the nanometric range.
- EDS Analysis has revealed that carbon, oxygen and iron are present in both the banana peel and the synthesized nanoparticles. The presence of iron is more in the banana peel than the nanoparticles. From banana peels, iron has a percentage value of 57.10% and 77.85% value from the nanoparticles.
- The presence of nanoparticles in the applied coating improved the hardness, adhesion and other properties of the coating.
- The higher the amount of nanoparticles contained in the surface coating, the higher the abrasion resistance of the coated metal sample.
- The microstructural analysis results using SEM, TEM, EDX and FTIR showed the internal composition of the banana peel used to develop the nanoparticles and internal composition of the iron nanoparticles.

- The control coating helped in knowing the differences in properties compared to other concentrations which contained various concentrations of nanoparticles.
- Nanoparticles can be derived from banana peel and using it in surface coating gives results that are favorable.

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