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Preparation, characterization, and study of effect of particle sizes on different loading of polymer matrix composites using sugar-cane bark fiber

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Abstract: *Biodegradable, natural reinforced composite was developed from sugar cane bark and high density polyethylene. The sugar cane bark was separated from sugar cane stalk, washed with distilled water, dried, grounded and classified into 250 µm, 350 µm and 500 µm particle sizes. High-density polyethylene was reinforced with sugar-cane fiber in different loading: 0 g, 20 g, 40 g, 60 g, 80 g, 100 g of sugar cane fiber and 200 g, 180 g, 160 g, 140 g, 120 g, 100 g of polyethylene respectively. Melting of the polyethylene and mixing with sugar cane back was done in a Two Roll Mill machine before being transferred into a compressing moulding machine. The composites obtained were subjected to test of mechanical properties which include: impact resistance, tensile strength, flexural, hardness and water absorption (24 hours). The result shows that fiber-high density polyethylene bonding interface was stronger than the fiber-fiber interface showing decrease in the tensile strength, flexural strength and young modulus as filler loading increases while water absorption and hardness increase with increase in particle sizes. Particle sizes 250µm give the most regular and preferable results. The structure was determined using scanning electron microscope (SEM) and the functional group using Fourier transform infrared spectroscope (FTIR).*

Keywords*: Sugar cane, polyethylene*

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I. Introduction

Advances in composite research and development are shifting away from the utilization of synthetic based raw materials to utilization of biodegradable raw materials. Environmental and sustainability considerations are at the heart of this paradigm shift in utilization of biodegradable raw materials for composite development (Nguong, Lee & Sujan, 2013). This millennium has witnessed great achievements in green technology in the area of materials science via the development of high-performance materials (reinforced composites) made from natural resources (Nadali et al., 2010). A need for waste control, more sustainable methods of production and reduced energy usage are the main factors responsible for the replacement of synthetic fiber reinforced composites (glass, carbon and synthetic fibers) (Faruk, et al. 2012). Thus, material components such as lignocelluloses fibers and biodegradable polymers are viable alternatives for the fabrication of new biodegradable composites or bio composites. The development and assembly methods for natural fiber reinforced polymer composite materials and the patterns are required to meet economy and performance targets (Nechwatal, Mieck & Reubmann, 2003). Research has seriously been carried out on recyclable materials from sustainable resources for a different type of applications (Raj, Kokta & Daneault, 1990). This has been affected by an increasing rate of demand for lighter-weight, stiffer, recyclable, cheap and stronger materials in an area such as aerospace, construction, packaging and transportation industries. Improving environmental awareness all over the world has seriously impacted materials engineering and design and therefore moved the researchers towards designing materials that are environmentally friendly (Rout et al., 2001). This brings about the emergence of a new type of materials a change from non-degradable, to renewable and easily degradable materials.

Sugarcane shaft is very good example of renewable and degradable material with huge potential application in composite development. The sugarcane shaft consists of a hard fibrous substance called rind while inside is soft material called pith. The pith contains small fibers and the majority of the sucrose, while the rind contains longer and finer fiber, arranged randomly throughout the stem and bound together by lignin and hemicelluloses. It is reported that fibers are often located adjacent to the inner wall of the rind particle (EL-Tayeb, 2008). Its waste that usually burnt in the fields as means of disposal are currently used as fillers/reinforcements in polymer to develop new engineering composite materials for different applications. The extensive use of these fibers is a function of their well-defined structural and mechanical characteristics which are being affected by the locality in which they originate, age of the plants and the climate conditions (Rena, 1997)

Polyethylene is a type of polymer that is thermoplastic and chemically synthesized from ethylene a compound made from natural gas or petroleum (Saini & Shenoy 1985)). Its environmental impact concerns, recycling may reduce this problem since polyethylene scrap can be melted down and reused. Due to its recyclability and ability to melt, it can further be used as a matrix in the development of natural reinforcement composites (Luz, Caldeira-Pires, & Ferrao, 2010)

Apart from this, the increasing focus on eco-friendliness such as the European Union's directive that all new vehicles must use 95% recyclable materials to meet the "end of life" needed by 2015 has led to greater interest for the manufacture of commercially viable biodegradable composites. (Kestur, 2009). Due to these drawbacks, attention shifted from synthetic fiber to natural or renewable fibers. It can be noted that many leading plastics companies in U.S and other western countries are leading in fabricating biodegradable materials from natural materials. (Kestur, 2009)

Composite materials are currently play significant role due to the fact that they are not heavy in weight and better corrosion resistance. They usually consist of a polymer matrix in which fibers are uniformly distributed. The mechanical properties of particulate filled into polymer composites is a function of the size, shape and distribution of filler particles in the polymer matrix and good compatibility at the interface of the polymer matrix and particle surface (Zhong, et al., 2006) and (Zuqiang et al., 2012)

The basic goal in the development and application of reinforced materials is to achieve a good result from the composite materials. Undoubtedly, there is quite a number of agricultural by-products abundance in the country, while studies are being conducted to explore the usefulness of some of them, a lot still remain untouched. Common among them are groundnut shell, sugar cane bark etc. Previous works used bagasse and little or no work has been reported on the use of sugarcane bark. This research thus focus on the use of sugar cane bark as filler in the development of natural reinforced composite and equally seeks to used compression mold with thermoplastic, precisely, high density polyethylene, as a matrix to develop composite. Determination of the effects of particle sizes at different loading on the physiochemical properties of the fabricated composite were carried out.

II. Materials And Method

The major materials employed in this work and their sources are tabulated in Table 1. The Equipment, the equipment model and the sources are listed in Table 2.

Table 1: The Materials

S/NO	MATREIALS	SOURCES
1	Sugarcane bark	Gwadebe market behind U.K Bello Minna, Niger State
2	High Density Polyethylene	Pure Chemical products Ltd , Needhan Market Suffolk England

Table 2: The Equipment

S/NO	EQUIPMENT	MANUFACTURER/MODEL	SOURCES
1	Two roll mill	Reliable Rubber and Plastics Machinery Company , New Jersey, U.S.A (Model 5189)	NILEST, Samaru Zaria. Kaduna State
2	Hydraulic Hot press	Carver Inc., Wabash, U.S.A (Model 3851-0)	NILEST, SAMARU Zaria. Kaduna State
3	Sieves with particle sizes 250µm, 350µm and 500µm		Ahmadu Bello University (ABU) Zaria Kaduna State
4	SEM Machine	PhenomProX, PhenomWorld in Eindhoved Netherlands	Ahmadu Bello University (ABU) Zaria Kaduna State
5	Mechanical grinder		PZ market, Niger State
6	Morta and pestle	Locally fabricated	Sabon-Gari Minna, Niger State
7	Hardness tester	MuverFranscisco, Munoz Irles. (Model 5019)	NILEST, SAMARU Zaria
8	Beakers	Pyrex 600m l Clifton, England	National Research Institute for Chemical Technology (NARICT) Zaria, Kaduna State

9	Weighing balance	Kerro made with Japanese Technology, (Model BL3003) Made in Taiwan	National Research Institute for Chemical Technology (NARICT) Zaria, Kaduna State
10	Impact tester	CeastResilImpactor P/N 6957.000	NILEST, Samaru Zaria. Kaduna State
11	Oven		National Research Institute for Chemical Technology (NARICT) Zaria, Kaduna State
12	Saw blade		Samaru market, Zaria
13	Spatula		NARICT, Zaria
14	Stop watch		
15	Mold		NILEST, SAMARU Zaria. Kaduna State

Fig 1: Sugar canes bark

2.1 Collection of sample

High density polyethylene used in this work was obtained from Steve-more chemical shop Zaria, Kaduna State. Fresh sugarcane waste was collected locally from Gwadebe market located at UK Bello road, Minna, Niger state. To ensure good result and quality of product, some physical operation were carried out on the sample. The brown part (upper skin) was removed by scrapping using knife without damaging the fiber surface; hence thoroughly washed with distilled water to remove dirt that might be attached to it and spread on a water proof sheet under the sun for one week to reduce the moisture content and therefore stored in a clean polythene bag. Because sugarcane bark samples were properly sundried, that make it free of fungi grows during storage. Then the fibers were dried in an Oven at a temperature of 120^{O}C to further dry the sample to about 99.5%. The required drying time was determined by weighing the sample every fifteen minutes until constant reading was obtained. . Size reduction was carried out using mortar and pestle and crushing machine.

The powder particle size distribution was determined by shaking the screens. The basic analytical method involves shaking the sieves on top of one another in ascending degrees of coarseness and then placing the test powder on the top sieve. Sieves are selected to cover the entire range of particle size present in the test. The nest of sieve was arranged with the coarses screen at the top and the finest at the both. The product from an intermediate grinder passes through the mesh size as follows 500µm, 350µm and 250µm.

2.2 Preparation of high density polyethylene

High density polyethylene was reinforced with sugar-cane fiber in different loading: 0g, 20g, 40g, 60g, 80g, 100g of sugar cane fiber and 200g, 180g, 160g, 140g, 120g, 100g of polyethylene respectively

The melting of high density polyethylene and mixing with filler was done according to the ASTM method. The two roll mill were switched on and the temperature was set at 170^{o}c for after an hour the temperature reached 170^{0}C then the motor was on and the two roll were rolling against each other. High Density Polyethylene was poured in between the rollers while the nip Adjuster was to adjust the size of the roller to achieve a desirable thickness of the material. Handsaw was used to shape composite to fit into the mould and foil paper were placed on the mould to facilitate easy removal of the composite from the mould.

After that the material were put inside the injection moulding machine and the temperature was set to 150^{o}c for an hour, pressed for 5mins and finally removed.

2.3 Testing

The mechanical properties of the composite such as tensile strength, water absorption, flexural strength, SEM, FTIR, impact strength and hardness were conducted according to ASTM standards. Analysis of variance test were runned on the results of different loading and particle sizes to know if the results different are scientifically significant or not.

III. Results And Discussion

The graph of Tensile strength (Fig. 2) shows that fiber-high density polyethylene bonding interface was stronger than the fiber-fiber interface showing decrease in the tensile strength as filler loading increases. 250µm gives the maximum tensile strength because it absorbs high density polyethylene and properly mixed that gives it the ability to stand the pull but later dropped because of fiber-fiber interface. 350µm at loading 80g may be as a result of improper mixing that makes the fiber to cluster (Figure 12). There was a decrease as particle sizes increases. This was recorded by Nwanonenyi et al (2015). The maximum tensile strength was recorded for particle size A(250µm).

From the Fig. 3, the high density polyethylene-fiber interface bond has more ability to carry the load at loading 20g. 250µm gives maximum young modulus followed by 500µm to 350µm. The point at loading 80g may be a result of portion used for the test (Figure 12). Young modulus was found to decreases as the particle sizes increases. Maximum young modulus was recorded by particle size A (250 µm). From the result above shows that particle sizes below 250 µm will give higher result. The graph in Fig.4 shows maximum extension at loading 40g for the three particle sizes. 500µm particle size has maximum extension followed by 250µm and the graph shows maximum extension at HDPE-fiber interface. There was a decrease as particle sizes increases. The maximum extension was produced by particle size A (250 µm)

Particle sizes 250µm and 500µm records maximum flexural strength at loading 20g of fiber and from the graph (Fig. 5), it shows that 250µm with large surface area that absorbed more HDPE was more favorably with flexural strength. 350µm at loading 80g may be as a result of non-homogeneity in mixing might cause that high flexural strength (Figure 12). Flexural strength was found to decrease as the particle size increases. The maximum flexural strength was produced by particle size A(250 µm), showing that the smaller the particle size, the higher the result. Particle size 250µm produced the maximum flexural strength.

The maximum strain was recorded on loading 160/40 and the result (Fig. 6) shows that as the filler loading increases, the strain decreases. The extension was weak at fiber-fiber interface favorably HDPE-fiber interface for large production at loading 40g. The maximum strain was produced by particle size C (500 µm).

From the graph (Fig. 7), particle size 500µm absorbed water more than other particle sizes because of the bigger particle size of the fiber that it couldn’t absorb much HDPE and the graph shows that the bigger the particle size the more the water absorbed. Absorption of water in an unfilled sample might be because of introduction of air to HDPE during mixing. Water absorption capacity was found to increase as particle size increases. Maximum water absorption was displayed by particle size C (500µm) and the least by particle size A (250µm). Particle size 500µm absorbed water more than other particle sizes.

Maximum hardness was recorded on loading 60g of fiber in all the particle sizes (Fig. 8). 250µm particle size been higher than 350µm particle size at loading may be as a result of improper mixing or at a point that was used for the test. 250µm particle size has higher surface area and absorbed HDPE which makes the material to be lesser while 500µm has less surface area that makes it not to absorb HDPE uniformly to the fiber makes it to be harder. The effect of particle size on hardness increases with increase in particle sizes in the study. Maximum hardness was displayed by particle size C (500µm) and the minimum by particle size A (250µm).

The graph in Fig. 9 shows the deformity as a result of impact. 250µm has the maximum impact because of its large surface area it absorbed more high density polyethylene while 500µm that has small surface area than other has less impact because it does not absorbed much of high density polyethylene. The maximum impact was recorded on loading 40g of fiber. The effect of particle size on impact resistance did not follow a regular pattern in the study. Maximum Impact was displayed by particle size A (250µm) and the minimum by particle size B (500µm).

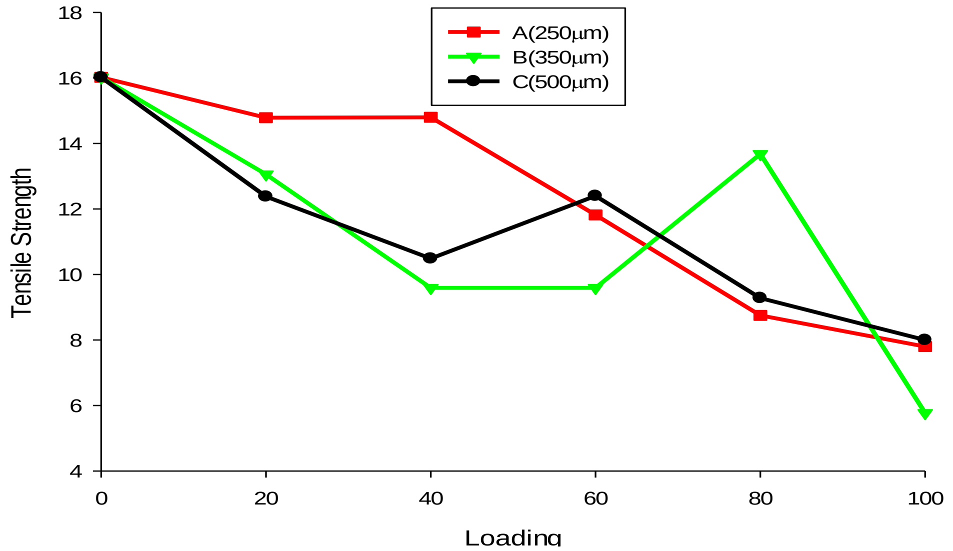

Fig 2: Tensile Strength

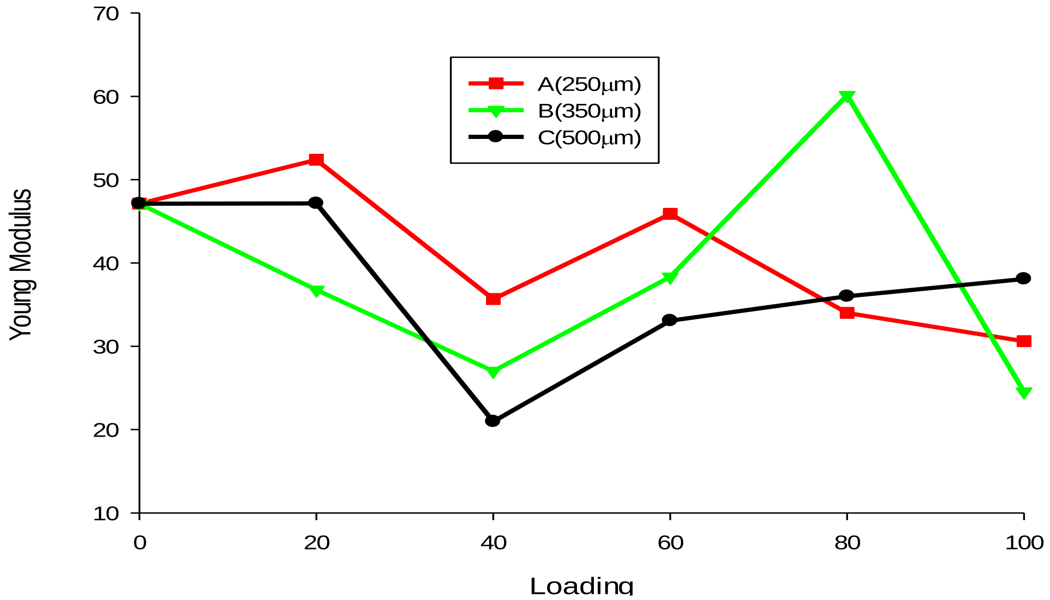

Fig 3: Young Modulus

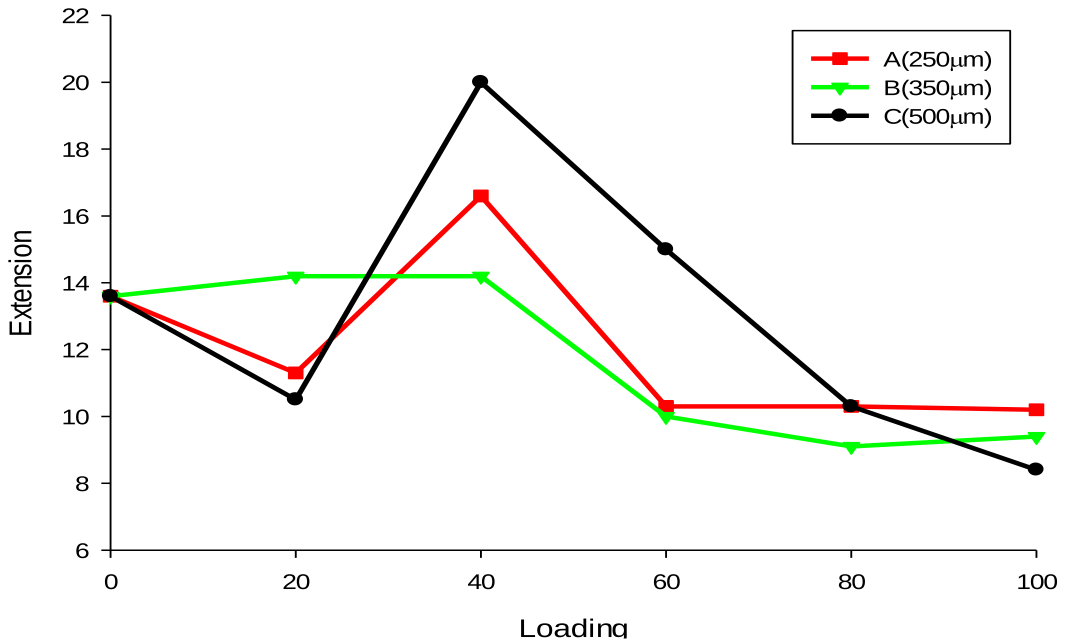

Fig 4: Extension

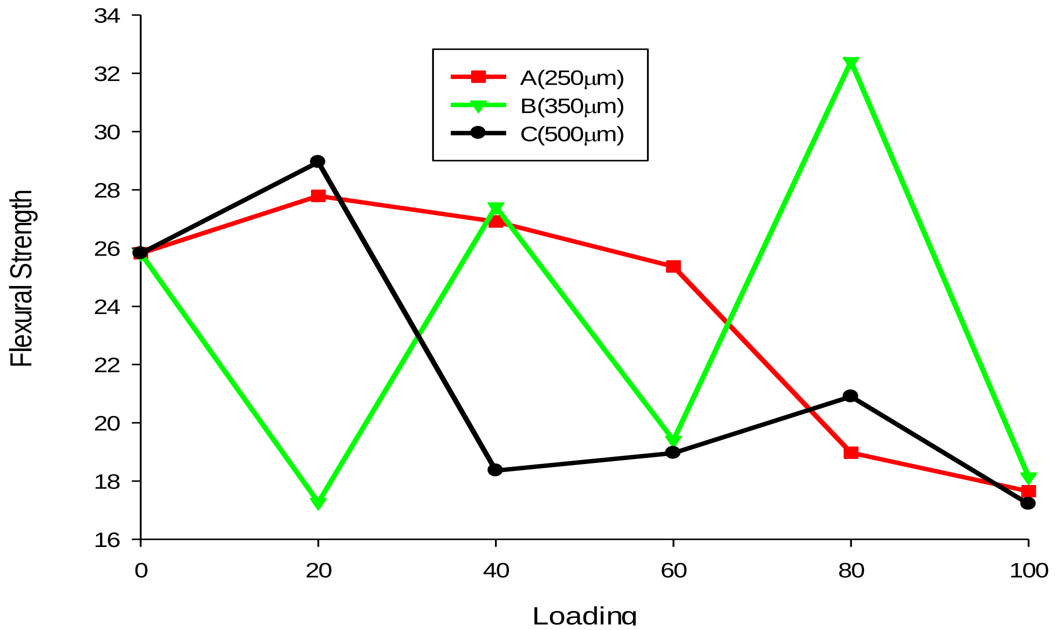

Fig 5: Flexural Strength

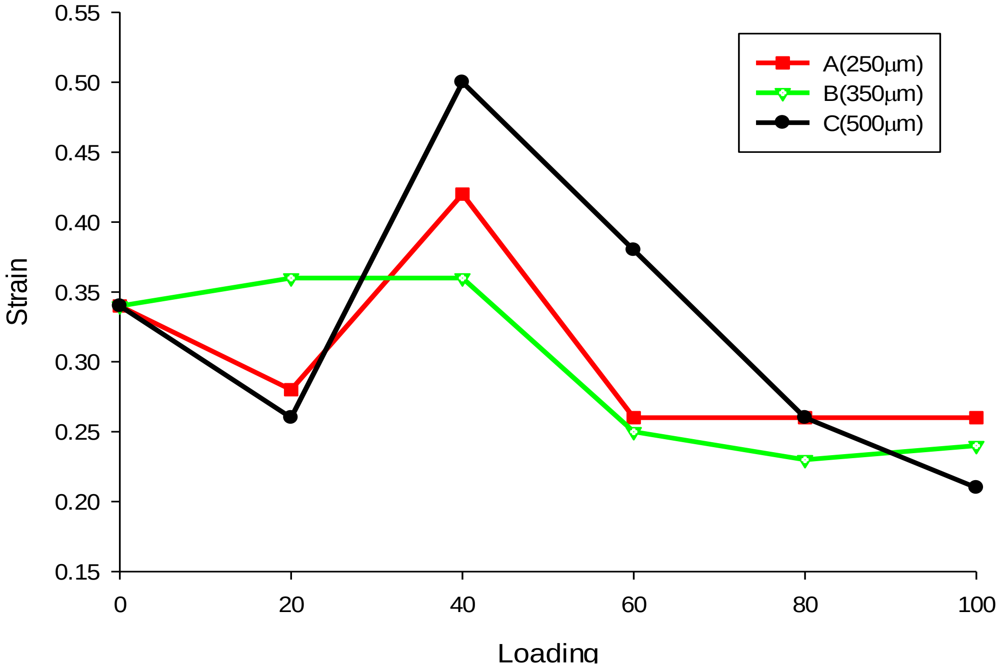

Fig. 6: Strain

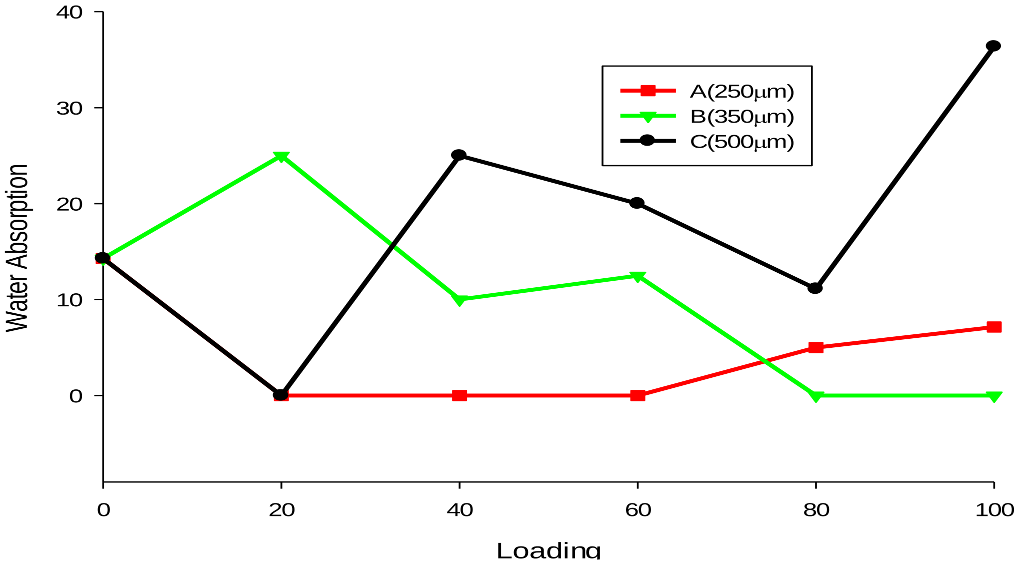

Fig. 7: Water Absorption

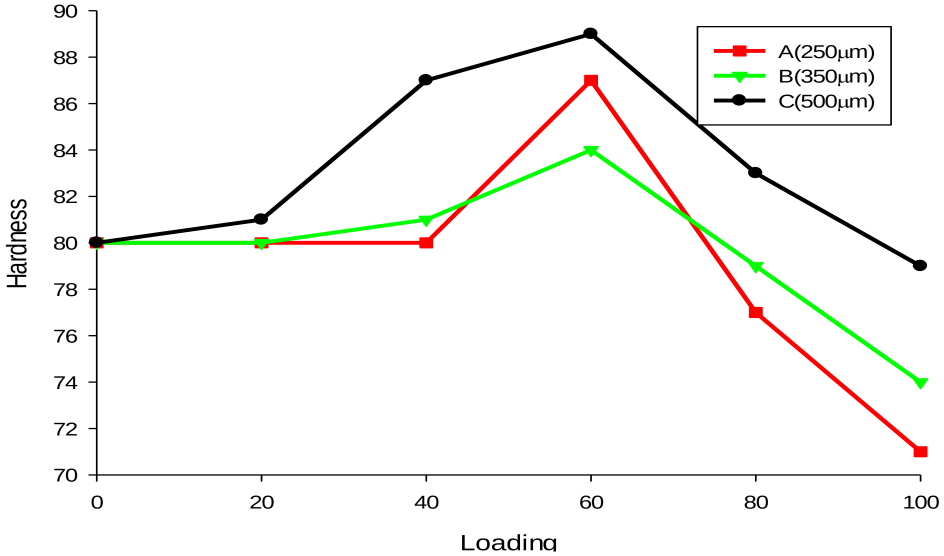

Fig. 8: Hardness

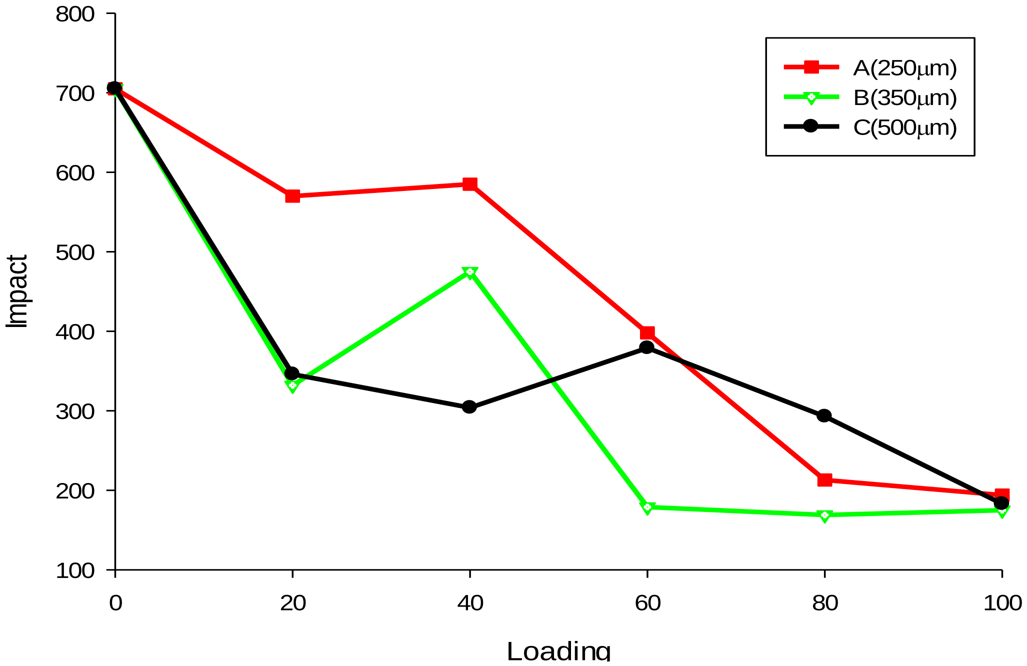

Fig 9: Impact

3.1 Scanning Electron Microscope (SEM) Results

Scanning Electron Microscope of type PhenomProX, PhenomWorld was used to analyze the sample at magnification of 500X. Figures 10, 11, 12 and 13 were the SEM results that show the structure of the produced composite of unfilled sample and loading 120/80 in each particle sizes. It was seen that unfilled sample has a smooth texture and very little number of pores. The little pores seen might be as a result of air introduced during mixing. Micrograph of the high density polyethylene filled with loading 120/80 of 250µm particle sizes as shows a uniform distribution but several numbers of scattered fibers and pores that might be as a result of introduction of air formed during mixing. Micrograph of high density polyethylene filled with loading 120/80 of 350µm particle sizes shows inhomogeneous mixing that may be as a result of improper mixing that causes the filler cluster within the polymer matrix. Figure 13 of loading 120/80 of 500µm particle sizes shows higher number of pores and surface roughness. Unfilled sample shows smooth texture when compared to others.

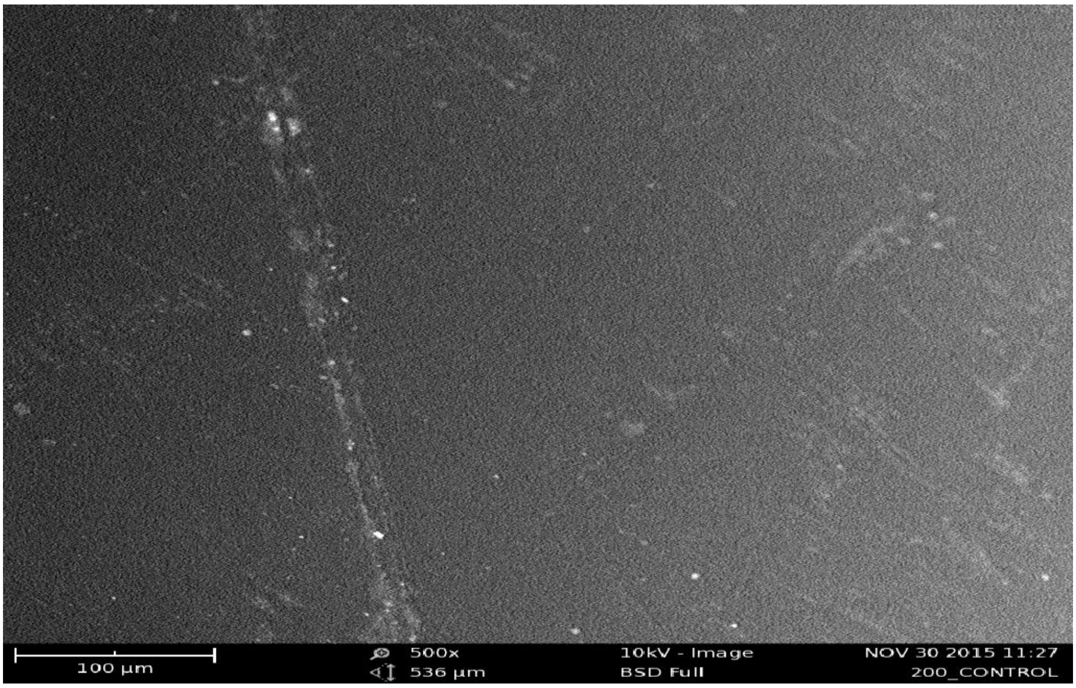

Fig 10: SEM results obtained from (unfilled sample) loading 200/0

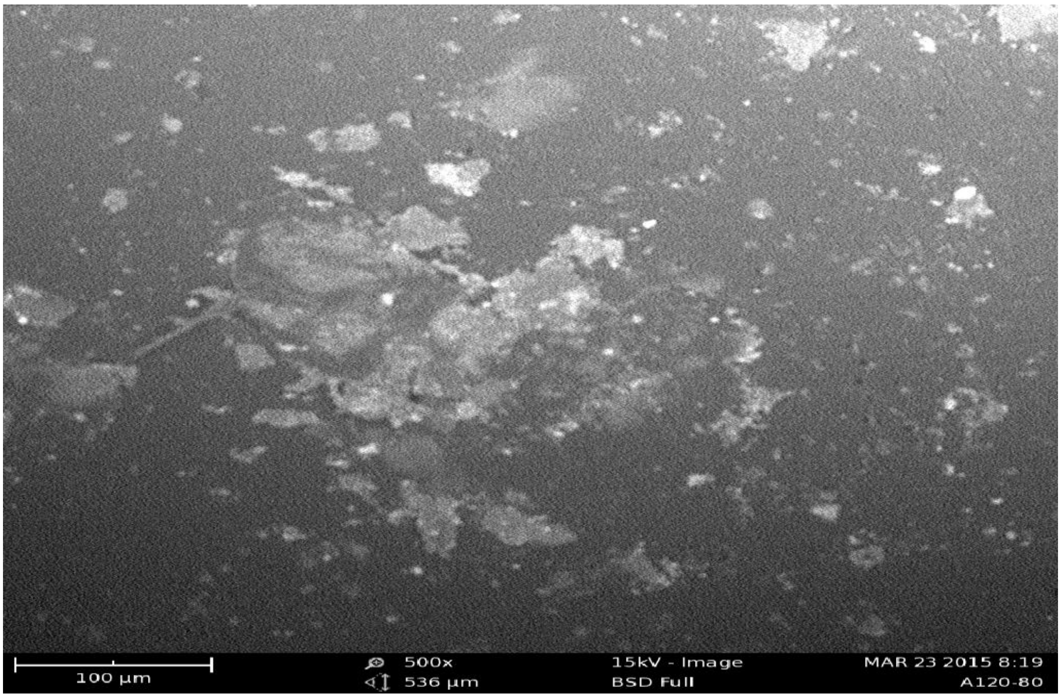

Fig 11: SEM results obtained from particle sizes A(250µm) and loading 120/80

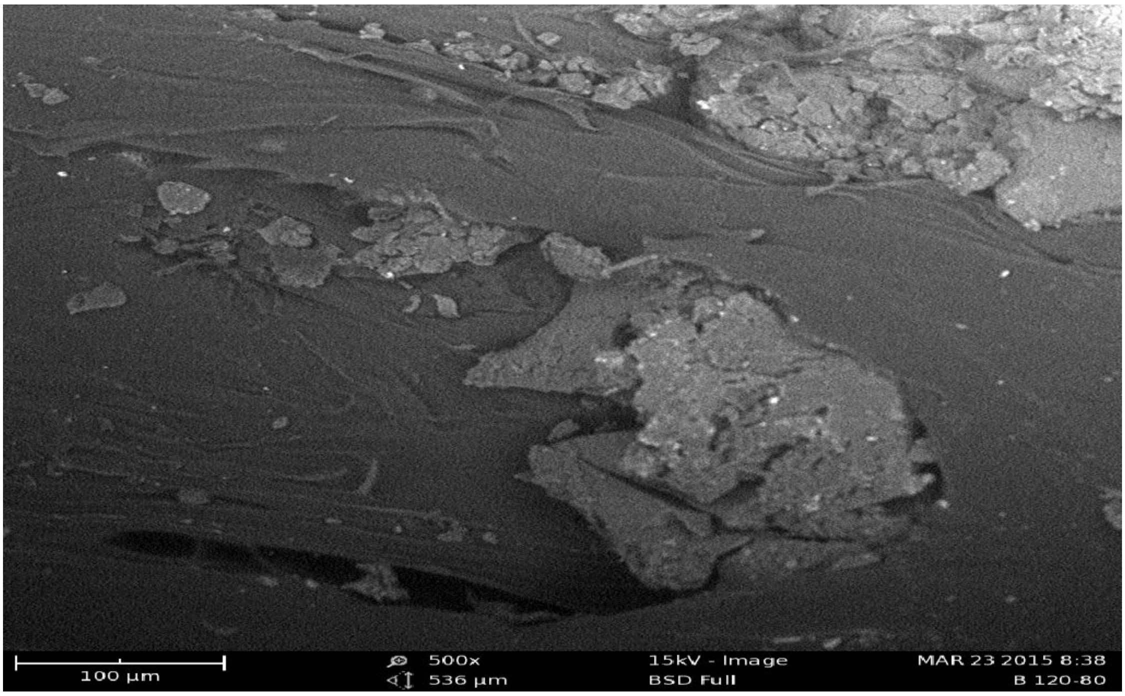

Fig 12: SEM results obtained from particle sizes B(350µm) and loading 120/80

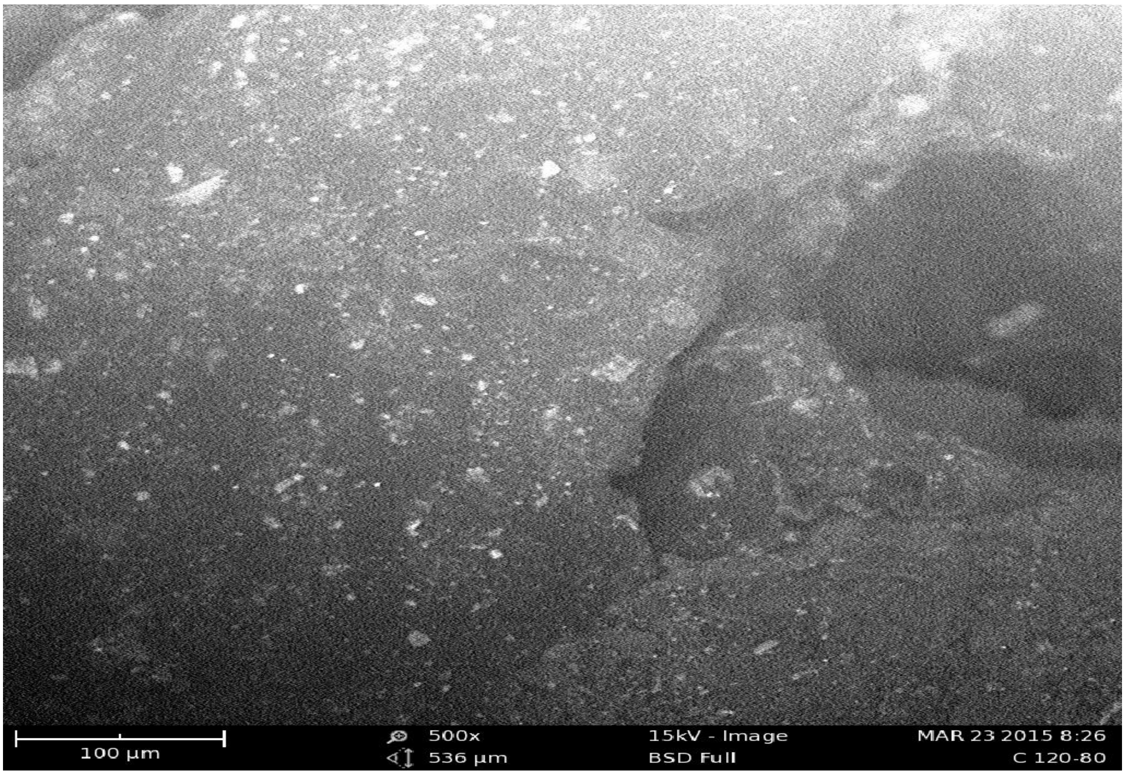

Fig 13: SEM results obtained from particle sizes C(500µm) and loading 120/80

3.2 Fourier Transform Infrared Spectrophotometer (FTIR) Results

Figure 14 shows the FTIR test results of particle size 250µm and the loadings. The result shows that all was broad except loading 160/40 that was strong and broad at the same time (partially take part in chemical reaction) and the functional group is (O-H) hydroxyl group. The functional group been broad means that it is inactive in chemical reaction. Figure 15 shows FTIR test results of particle size 350µm and the loading. It was seen from the result that loading 140/60 functional group is strong and belong to (C-H) hydro-carbon group while other loadings are broad, functional group (O-H). The sharpness of the peak in loading 140/60 indicates that the substance is active in chemical reaction by the presence of the functional group. Figure 16 shows the

FTIR test results of particle size 500µm and the loadings. The result shows loading 140/60 to be strong while other loadings are broad but all belong to functional group (O-H) hydroxyl group. O-H group is a functional that was found in the sample. The functional group is the active part of a compound. All loading in particle sizes 250µm have O-H functional group while only loading 140/60 in 350µm and 500µm have C-H functional group means all have the same functional group in respective of the particle sizes.

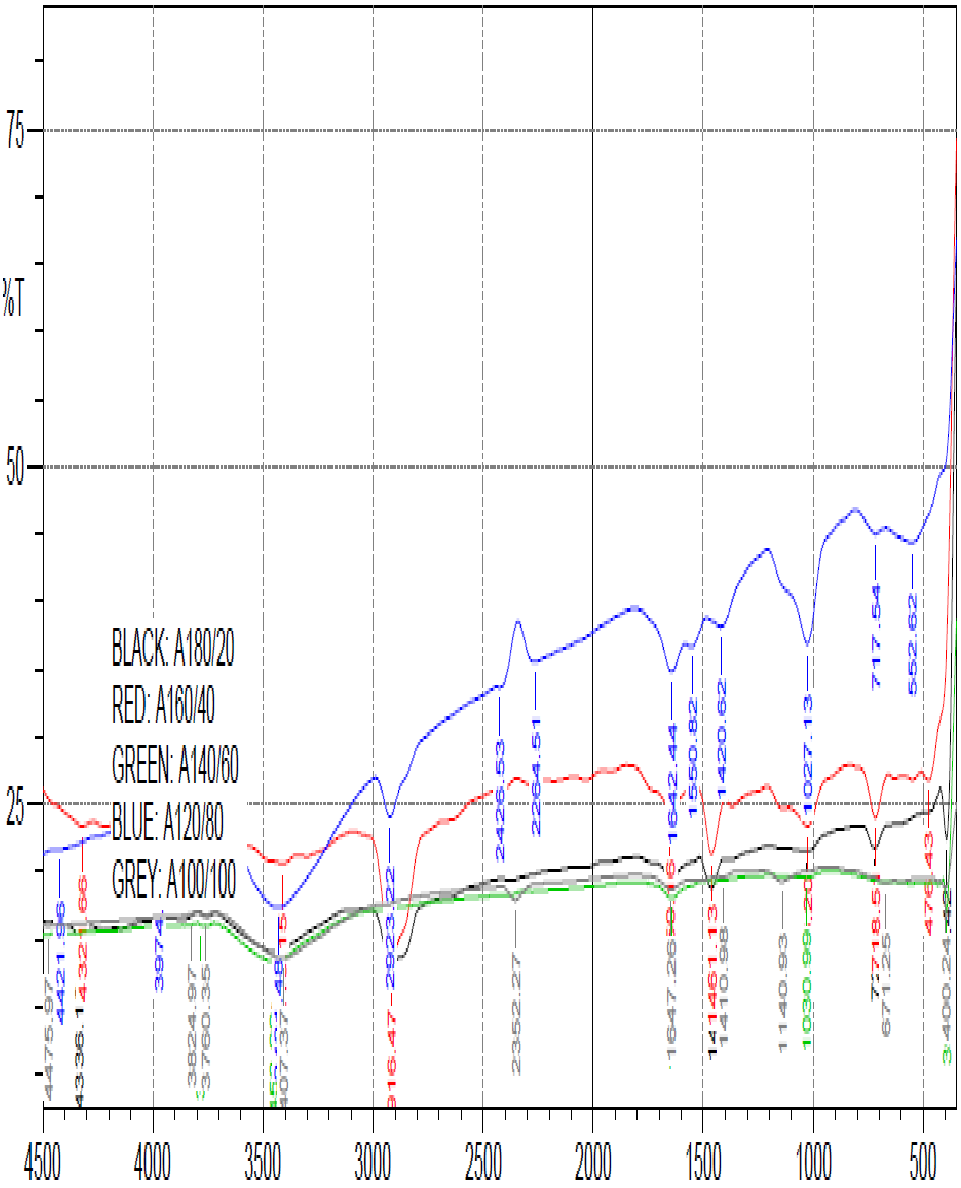

Fig 14: FTIR results obtained from particle sizes A(250µm) and the loading

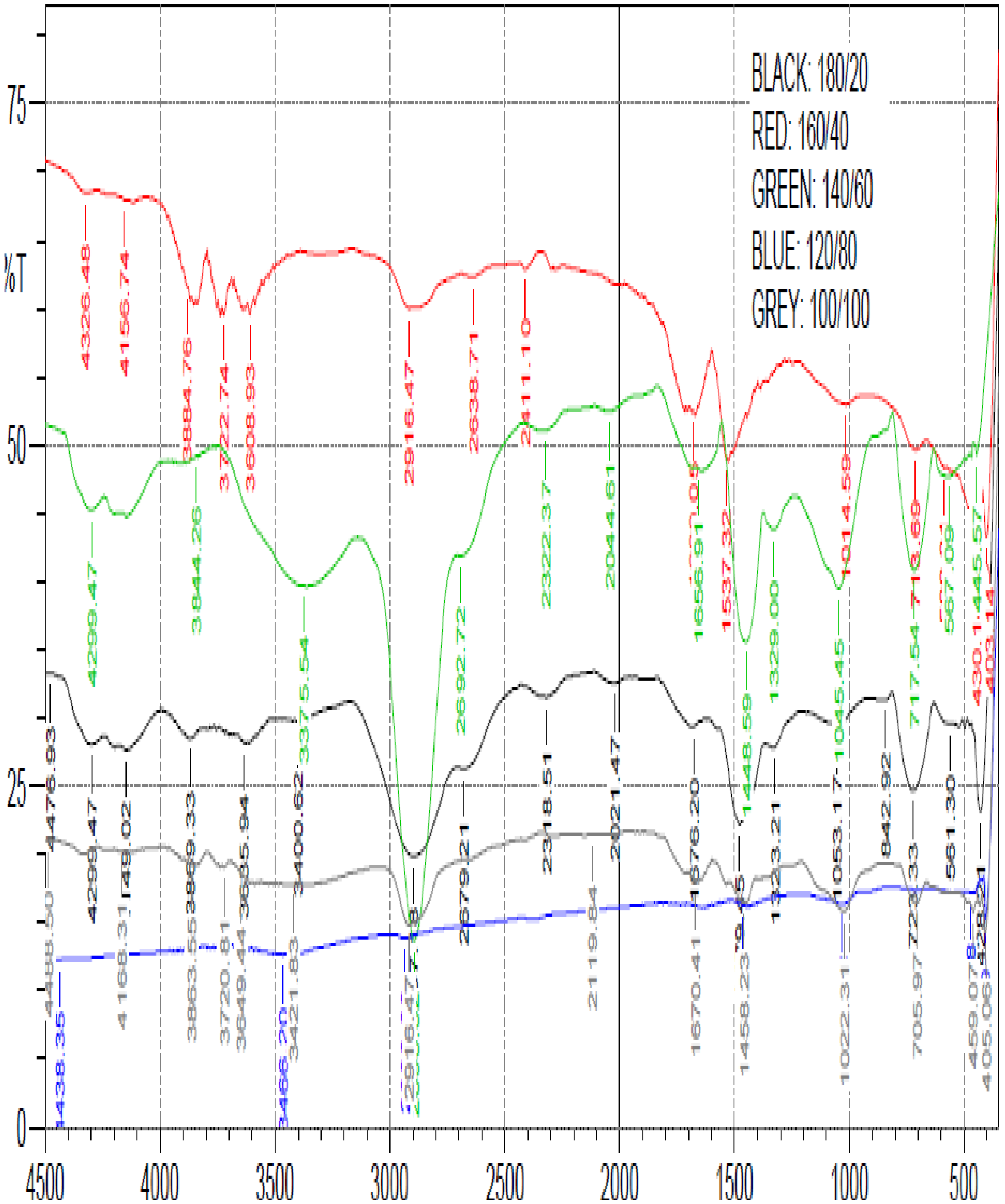

Fig 15: FTIR results obtained from particle sizes B (350µm) and the loading

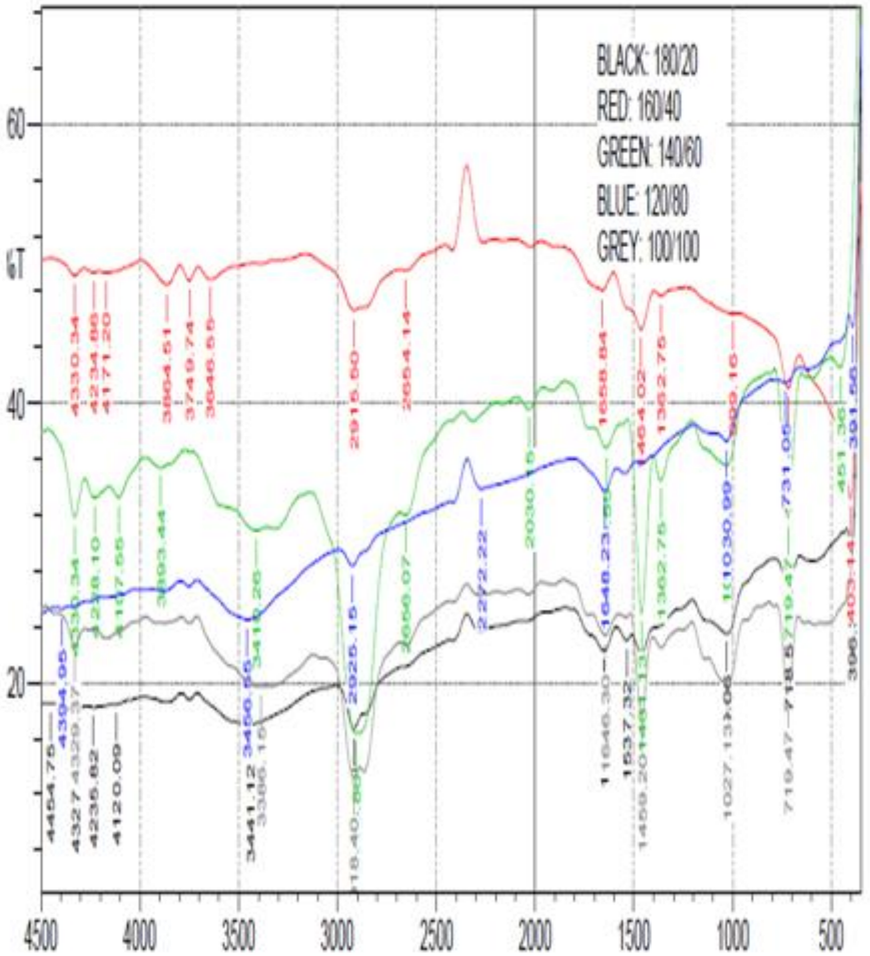

Fig 16: FTIR results obtained from particle sizes C (500µm) and the loading

IV. Conclusion

This work presents the composites prepared with various amounts of high density polyethylene and sugar cane bark fiber loading. The waste agricultural by-product (sugarcane bark) was employed as a raw material with high density polyethylene for the preparation of composite was successfully done. Composite properties, fiber particle sizes at different loading rate on high density polyethylene were investigated. The graph in Appendix shows that fiber-high density polyethylene bonding interface was stronger than the fiber-fiber interface tensile strength, impact, young modulus, extension and flexural strength. 250µm gives the maximum tensile strength because it absorbs high density polyethylene and properly mixed that gives it the ability to stand the pull but later dropped because of fiber-fiber interface. Particle sizes 350µm on flexural strength, tensile strength and young modulus at loading 80g of fiber may be as a result of improper mixing (see SEM result). The tensile strength and impact was found to decrease with the increase in filler loading except in some figures which may be as a result of inhomogeneous mixing. Also, the hardness result was not favorable with loading 120/80 and above irrespective of particle sizes. Practically, in this work, the particle sizes 250µm give the most regular and preferable result that draw to my conclusion that the smaller the particle sizes the better the results.

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