

A STRUCTURAL STUDY OF POLYMER COMPOSITE REINFORCEMENTS USING AGRICULTURAL WASTES FOR AUTOMOBILE BRAKE-PAD APPLICATIONS

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Abstract

Despite the advancement in materials engineering and the potential for use of agricultural wastes as composite material for brake pas, their rich diffractive pattern, phase identification and thermal stability properties have been downplayed. Consequently, this study conducts experiments on a select number of reinforcements, namely orange peels, coconut, periwinkle, palm kernel and egg shell particles for information on their diffraction patterns, thermal stability and phase identification. The diffraction test was carried out to reveal the crystalline features of the raw particles while the phase identification helped to specify the phases with respective scores. The thermal stability permitted the revelation of thermo-gravimetric features of the particles, for ascertaining the aptness of the particles for temperature usage. It was found that (1) coconut and palm kernel shell particles are amorphous, orange peel particles are of amorphous order with some crystalline arrangements; periwinkle and egg shell particles maintained regular crystalline order in their structures; (2) The thermal stability results showed that orange peel, coconut and palm kernel had a glass transition between 300-310°C, while periwinkle and egg shell particles exhibited glass transition of 680 and 710°C, respectively, (3) The periwinkle and egg shell particles reached the highest withstanding temperature (HWT) of 800°C, even as the orange peel, coconut and palm kernel particles attained a HWT of 1,000°C before final disintegration. The selected agro-waste materials can be used as substitutes for asbestos in automobile brake pad manufacture.

Keywords: Asbestos, agro-waste materials, identification of phases, diffraction pattern, thermal stability

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Introduction

The structural study of polymer composite is concerned with a group of experiments to analyze the richness of materials in terms of responses to diffraction, thermal stability and phases present in the material for score ranking (Ponomarenko *et al.*, 1999; Volkova and Kalistratova, 2015; Ferreira *et al.*, 2017). These analyses position a material against another for suitability in use in composite development (Volkova and Kalistratova, 2015). In a structural study, the choice of experimental test is made as a solution to the structural enquiry and the material and the superior value is selected as the preferred material in the tests. Nonetheless, the requirement for the structural study of automobile brake-lining material dates back as 1897, when Herbert Froad invented the first brake lining material (Nicholson, 1995; Kurt and Boz, 2005; Mohanty and Chugh, 2007; Matějka *et al.*, 2010; Sellami *et al.*, 2014). Structural study is a twin-action in the brake frictional material analysis; efforts at understanding structural studies of brake lining material have been revealed in 1908 (Shinde and Mistry, 2017). More recent outstanding contributions on brake material could be found in Sheehy *et al.* (1989), Lemen (2004), Kakooei and Marioryad (2010), Aku *et al.* (2012), Straffellini *et al.* (2015), Hagino *et al.* (2016), Yawas *et al.* (2016), Shinde and Mistry (2017), Yakubu *et al.* (2013), Venkatesh and Murugapoopathiraja (2019). Interestingly, the use of agro wastes has led to the discovery of some notable green composites (Aku *et al.*, 2012; Yakubu *et al.*, 2013; Abutu *et al.*, 2018; Fono-Tamo, 2018; Pujari and Srikan, 2019). Consequently a number of interesting responses have been made by some scholars (Ajibade *et al.*, 2015a,b,c, 2016a,b,c, 2017a,b,c; Öktem *et al.*, 2018). Scholars have revealed information on wear, water absorption and optimization potentials of reinforcements and composites made up of particulate orange peel, coconut shell, periwinkle shell egg shell and palm kernel (Ajibade *et al.*, 2015c; Pujari and Srikan, 2019). In this research, the problem statement is that there are no studies to reveal the structural details of these mentioned

reinforcements; paucity of diffraction pattern studies, phase identification research and thermal stability investigations exists till date on them. To tackle this problem, the current study launched an investigation on the diffractive pattern, phase identification and thermal stability of particulate orange peel, periwinkle, palm kernel, egg shell and coconut shell.

In this paper, the authors decided to investigate the structural issue concerning agricultural wastes for specific materials (namely orange peels, coconut shell, periwinkle shell, palm-kernel shell and egg shell) that may be used as polymer composite reinforcements. The focal issues are restricted to diffraction patterns, phase identification and thermal stability. This domain of composite material development came about for several reasons. Globally, there is intense pressure on brake pad manufacturers to abandon the use of asbestos-based brake pads. A research reported in 1989 by National Institutes of Health documented a report, which revealed that an elevated population of brake auto-mechanics was influenced with pleural and peritoneal mesothelioma that is associated with asbestos exposure. The asbestos employed in brake pad was reported to discharge gases that are hazardous to health after the use of brake pads. Thus, with the global target of discarding the use of asbestos materials, manufacturers are seeking for alternative materials. Furthermore, with the inflation worldwide that affects automobile spare parts, brake pad costs are exorbitantly high and the cost should be regulated for enhanced value-for-money by the consumers. So, alternative agro-based materials have potentials to displace the current materials used for brake pads.

In addition, the drive and incentive for environmentally conscious manufacturing globally is rewarding and several world class brake pad manufacturers are contemplating on green materials to reduce the effects of their manufacturing activities on the environment and become more competitive. In the area of

brake pad research, wear and frictional properties of brake pads have been the major topics of argument for scholars and they continue to discuss the influences of elemental compositions of brake pads on their wear performance (Laguna-Camacho *et al.*, 2005; El-Tayeb and Liew, 2009; Abbasi *et al.*, 2011; Kim *et al.*, 2011; Nirmal, 2013; Varrica *et al.*, 2013; Liew and Yevtunshenko and Och, 2014; Grzes *et al.*, 2016; Mat Lazin *et al.*, 2016; Yevtushenko *et al.*, 2017). However, since the evolution of agro-based brake pads, a growing research activity has defended the wear and frictional properties of agro-based brake pad, thus promoting its usage in automobiles (Idris *et al.*, 2015; Yawas *et al.*, 2016; Abutu *et al.*, 2018; Pujaris and Srikan, 2019). It is clear from the expanding literature on agro-based composites that numerous studies have considered the wear and mechanical properties of agro-based composites. Scholars have examined how the wear and mechanical properties of periwinkle shell (Yawas *et al.*, 2016), seashell (Abutu *et al.*, 2018), banana peels (Idris *et al.*, 2015) and palm-kernel shell (Pujari and Srikan, 2019) affect the field performance of composites developed from these reinforcements. Surprisingly, however, there has not been substantial attention given to the structural issues of these agro-based composites. Specifically, studies on diffraction pattern, thermal stability and phase identification of the agricultural wastes as reinforcements to composites in the production of brake pads are very difficult to find in literature.

Thus, from the evidence provided in literature, a wide range of research opportunities exists for coconut shell, periwinkle shell,

orange peels, palm kernel shell and egg shell as reinforcement materials in polymer composites. Thus, experimental analysis of these reinforcements will be pursued and this will take the form of usage of machines and analyzers.

Materials and Methods

Materials

The materials used in this investigation are processed particles from orange peels, coconut, periwinkle, palm kernel and egg shells. The orange peels, coconut, periwinkle and palm kernel shells were obtained local retailers in Akoka, Bariga and Oyingbo market areas of Lagos state, Nigeria while the egg shells were sourced from local fast food chains and kiosks in the aforementioned areas.

Methods

Diffraction Pattern and Phase Identification

The identification of the phases present and diffraction patterns were carried out with the use of a Diffractometer (Malvern Panalytical, X Pert Powder Diffractometer, UK) in the Department of Physics, University of Johannesburg, South Africa.

Thermal Stability Determination

A TGA (TA instruments, TGA Q50 Thermogravimetric analyzer, USA) in the Department of Physics, University of Johannesburg, South Africa was used to determine the thermal stability properties of the particulate materials. The thermal stability

Table 1. Identified pattern list for orange peel particles diffraction pattern

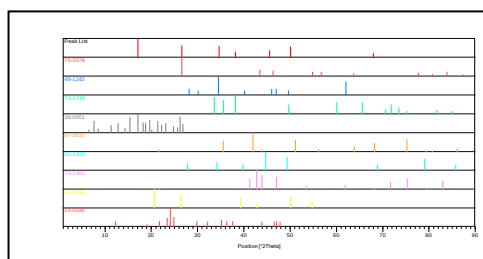
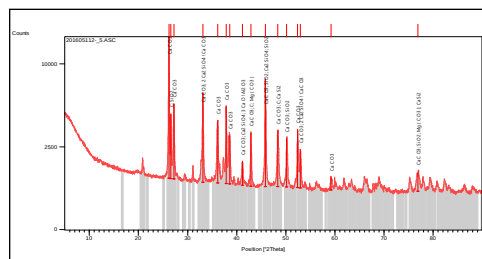
S/No	Visible	Ref. Code	Score	Compound name	Displacement (2Theta)	Scale factor	Chemical formular
1	*	49-1720	33	Fullerite	0.000	0.132	C ₆₀
2	*	39-0824	40	Aluminum Iron	0.000	0.110	Al ₈₆ Fe ₁₄
3	*	77-2151	34	Potassium Oxide	0.000	0.279	K ₂ O
4	*	75-0410	27	Diamond, syn	0.000	0.059	C
5	*	49-1719	24	Fullerite	0.000	0.307	C ₆₀
6	*	83-2074	30	Iron Silicate	0.000	0.253	Fe ₂ SiO ₄
7	*	50-1349	20	Silicon Carbide	0.000	0.079	Si ₅ C ₃
8	*	20-1115	16	Sodium Iron Oxide	0.000	0.039	NaFeO ₂
9	*	49-1720	33	Fullerite	0.000	0.132	C ₆₀

Table 2. Identified pattern list for coconut shell particles diffraction pattern

S/No	Visible	Ref. Code	Score	Compound name	Displacement (2Theta)	Scale Factor	Chemical formular
1	*	75-2078	71	Graphite	0.000	0.142	C
	*	46-1242	44	Silicon Oxide	0.000	0.081	SiO ₂
	*	73-1749	35	Moissanite 2\ITH\RG, syn	0.000	0.037	SiC
	*	38-0651	31	Silicon Oxide	0.000	0.577	SiO ₂
	*	87-2030	23	Magnesium Silicate	0.000	0.046	Mg ₂ (SiO ₄)
	*	50-1349	23	Silicon Carbide	0.000	0.052	Si ₃ C ₃
	*	79-1469	22	Diamond 4\ITH\RG	0.000	0.038	C
	*	43-0596	35	Silicon Oxide	0.000	0.538	SiO ₂
	*	14-0346	28	Magnesium Aluminum Silicate	0.000	0.458	MgOAl ₂ O ₃ SiO ₂

Table 3. Identified pattern list for periwinkle shell particles diffraction pattern

S/No	Visible	Ref. Code	Score	Compound name	Displacement (2Theta)	Scale Factor	Chemical formular
1	*	24-0025	70	Aragonite	0.000	0.738	CaCO ₃
2	*	26-1076	57	Carbon	0.000	0.272	C
3	*	46-1045	57	Quartz, syn	0.000	0.274	SiO ₂
4	*	01-1012	30	Calcium Silicate Oxide	0.000	0.150	Ca ₂ SiO ₄
5	*	01-1012	30	Calcium Silicate Oxide	0.000	0.150	Ca ₂ SiO ₄
6	*	80-2146	21	Silicon Oxide	0.000	0.090	SiO ₂
7	*	04-0640	30	Spurrite	0.000	0.156	2Ca ₂ SiO ₄ CaCO ₃
8	*	86-2329	23	Stishovite, syn	0.000	0.038	SiO ₂
9	*	86-2345	22	Magnesite	0.000	0.088	Mg(CO ₃)
10	*	86-2152	20	Calcium Silicon	0.000	0.029	CaSi ₂
11	*	01-1060	21	Calcium Aluminum Oxide	0.000	0.035	3CaOAl ₂ O ₃

**Figure 4. Plot of identified phases in coconut shell particles****Figure 5. Representative XRD diffraction pattern for periwinkle shell particles**

Periwinkle Shell Particles

The periwinkle shell particles were found to contain major diffraction peaks along the following positions, 26.18, 26.61, 27.20, 33.08, 36.11, 37.83, 38.57, 41.14, 42.87, 45.80, 48.36, 50.18, 52.39, 52.94, 59.23, and 76.91°. Their corresponding inter-planar distances are at 3.40, 3.34, 3.27, 2.70, 2.48, 2.37, 2.33, 2.19, 2.10, 1.98, 1.88, 1.81, 1.74, 1.72, 1.55, and 1.23 Å°. The corresponding score for the phases are

described by Table 3 and Figure 5. The diffraction pattern of the periwinkle shell particles reveals a significant presence of elongated peaks within the crystal structure of the particles. This indicates a very orderly arrangement of ions held in place by an unchanging intermolecular force, which correlates strongly with the findings of Yakubu *et al.* (2013).

Table 4. Identified pattern list for palm kernel shell particles diffraction pattern

S/No	Visible	Ref. Code	Score	Compound name	Displacement (2Theta)	Scale factor	Chemical formular
1	*	46-1045	69	Quartz, syn	0.000	0.788	SiO ₂
2	*	48-0708	36	Moissanite-8\ITH\RG, syn	0.000	0.049	SiC
3	*	50-0926	32	carbolite	0.000	0.442	C
4	*	02-1160	0	Mullite	0.000	0.156	3Al ₂ O ₃ , 2SiO ₂
5	*	80-0372	29	Stishovite	0.000	0.048	SiO ₂
6	*	32-0993	29	Silicon Oxide	0.000	0.178	SiO ₂
7	*	75-1621	24	Graphite 2\ITH\RG	0.000	0.071	C
8	*	27-0605	27	cristobalite, high	0.000	0.361	SiO ₂
9	*	14-0184	23	Magnesium Aluminum Silicate	0.000	0.106	4 MgO ₄ Al ₂ O ₃ 7SiO ₂
10	*	82-1553	23	Silicon Oxide	0.000	0.280	SiO ₂
11	*	83-2471	5	Quartz, syn	0.000	0.156	SiO ₂
12	*	88-2486	21	Stishovite	0.000	0.019	SiO ₂
13	*	85-0460	17	Silicon Oxide	0.000	0.134	SiO ₂
14	*	48-1449	17	Carbon	0.000	0.206	C ₇₀

Table 5. Identified pattern for egg shell particles diffraction pattern

S/No	Visible	Ref. Code	Score	Compound name	Displacement (2Theta)	Scale factor	Chemical formular
1	*	23-0528	26	Sodium Oxide	0.000	0.211	Na ₂ O
2	*	72-2091	21	Carbon	0.000	0.107	C ₈
3	*	45-1204	33	Aluminum Iron Silicon	0.000	0.339	Al _{0.7} Fe ₃ Si _{0.3}
4	*	03-0270	16	Cristobalite	0.000	0.389	SiO ₂

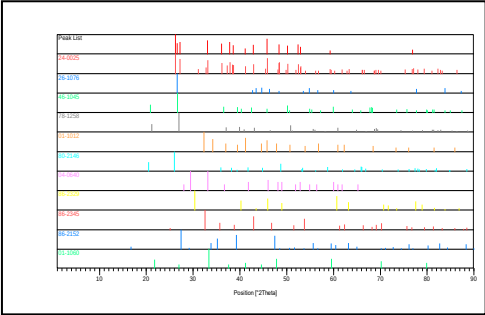


Figure 6. Plot of identified phases in periwinkle shell particles

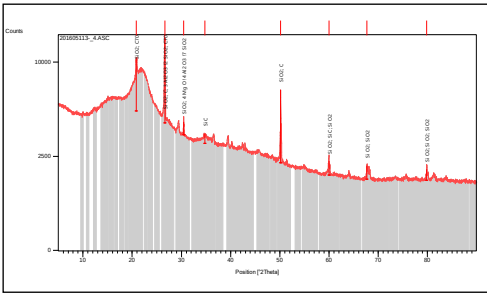


Figure 7. Representative XRD diffraction pattern for palm kernel shell particles

Palm Kernel Shell Particles

The major diffraction peaks of the palm kernel shell particles were found to occur on 20.85, 26.63, 30.47, 34.77, 50.16, 59.97, 67.71, and 79.83° while their corresponding inter-planar distances are 4.25, 3.34, 2.93, 2.57, 1.81, 1.54, 1.38, and 1.20 Å°. The phases identified in these peaks are quartz syn, moissanite, carbolite, mull ite, stishovite, silicon oxide and carbon. The respective scores for the phases are described in Table 4 and Figure 7. The palm

kernel shell particles diffraction pattern reveals broad peaks and short intensity peaks along the diffraction spectrum. Thus, the palm kernel shell particles are largely amorphous in nature with an irregular arrangement of atoms which agrees with the findings of Dagwa *et al.* (2012).

Egg Shell Particles

The major diffraction peaks found in the egg shell particles were found to occur on 29.61, 36.35, 44.61, 46.06, 48.64, 76.99, and

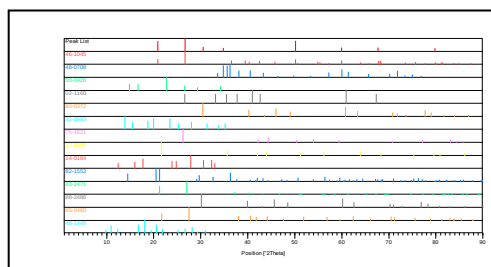


Figure 8. Plot of identified phases in palm kernel shell particles

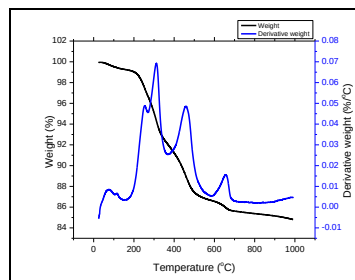


Figure 11. Representative TGA thermogram of orange peel particles

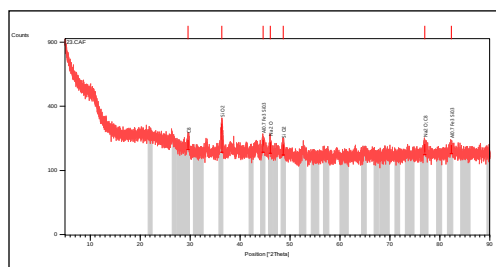


Figure 9. Representative XRD diffraction pattern for egg shell particles

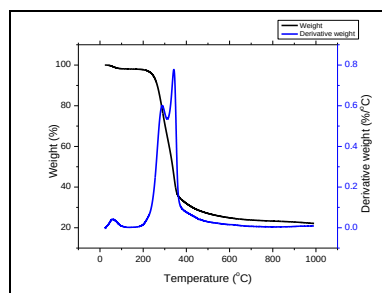


Figure 12. Representative TGA thermogram of coconut shell particles

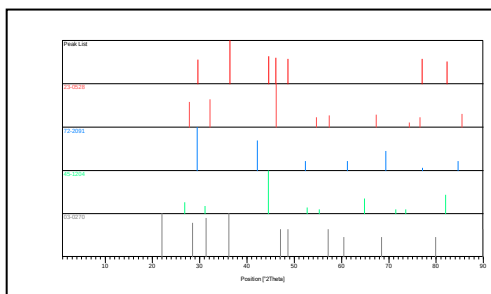


Figure 10. Plot of identified phases in palm kernel shell particles

82.32° having inter-planar distances of 3.01, 2.47, 2.03, 1.97, 1.37, 1.23, and 1.17 Å°. The phases identified with these peaks are sodium oxide, carbon, aluminium iron silicon and cristobalite. The respective scores for the phases are shown by Table 5 and Figure 8. The diffraction pattern of the egg shell particles is described in Figure 8 showing short elongated peaks which transverse the entire diffractogram

of the egg shell particles which is typical of a crystalline order.

Thermal Stability Determination

Orange Peel Particles

The thermogravimetric behaviour of the orange peel particles is described by Figure 11. The different stages of weight loss can be observed from the derivative weight loss curve, while the thermal disintegration is seen on the weight loss curve. The first point of inflection on the derivative weight loss curve is a broad peak around 100°C which can be attributed to the loss of moisture (water of crystallization). The curve is further characterized by elongated peaks which show the loss of volatile materials starting with hemicellulose around 300 to 350°C. The next points of inflection represent the loss of cellulose between 400 to 450°C and the giving

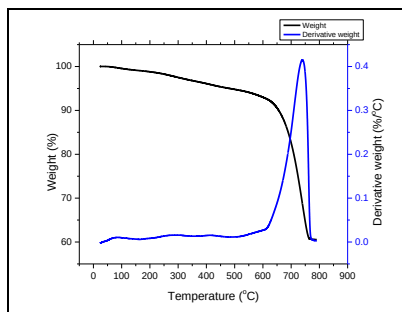


Figure 13. Representative TGA thermogram of periwinkle shell particles

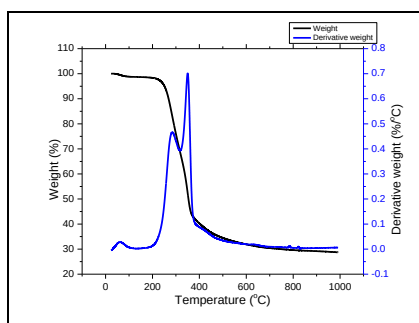


Figure 14. Representative TGA thermogram of palm kernel shell particles

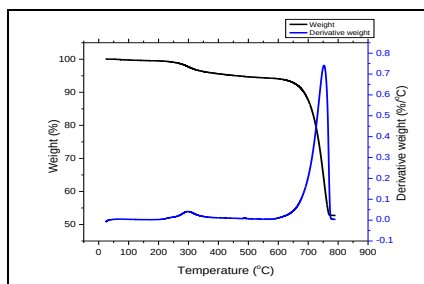


Figure 15. Representative TGA thermogram of egg shell particles

off of lignin material between 600 to 650°C. Thermal disintegration of the orange peel particles proceeds rapidly around 210°C. The particles experienced glass transition at 240 and 310°C. Overall, it experienced a weight loss of 17 % after final disintegration.

Coconut Shell Particles

Figure 12 describes the thermogravimetric behaviour of the coconut shell particles. The first point of inflection on the derivative weight loss curve is a small before the 100°C mark. This shows the escape of the water of crystallization traceable to the presence of moisture in the particles. This is followed closely by the loss of hemicellulose characterized by double elongated peaks between 250 to 400°C. The weight loss curve shows a gradual loss in weight between 0 and 200°C before a rapid loss in weight between 200 to 400°C. Although the material experienced a total weight loss of 90%, it experienced a temperature of 380°C before final disintegration at 980°C.

Periwinkle Shell Particles

The thermogravimetric behaviour of the periwinkle shell particles is described in Figure 13. The absence of peaks along the derivative weight loss curve indicates a lack of moisture and volatile cellulosic materials in the particles making it more stable. This is reflected on the weight loss curve by a gradual weight loss between 0 to 650°C. The derivative weight loss curve is characterized by an elongated peak between 650 to 770°C which represents the loss of the steady lignin. The material experienced a temperature of 680°C before experiencing total decomposition at 800°C. This correlates strongly with the reports of *Aku et al.* (2012) Overall, the periwinkle shell particles experienced a weight loss of 50 %.

Palm Kernel Shell Particles

Figure 14 describes the thermogravimetric behaviour of the palm kernel shell particles. The derivative weight loss curve reveals a small peak just before 100°C, which represents the loss of water of crystallization as a result of the presence of moisture in the palm kernel shell particles. The curve is further characterized by a pair of elongated peaks which represents the loss of unstable hemicellulose from the particles. The weight loss curve reveals a gradual thermal disintegration as the temperature increased from 0 to 220°C. The process of thermal disintegration was characterized with a rapid weight loss between 220 to 380°C. The

Table 6. Summary of thermal stability parameters of agro-waste particles

S/No	Agro-waste particle	Weight loss (%)	Glass transition temperature (°C)	Highest withstanding temperature (°C)
1	Orange peels	17	300	1,000
2	Coconut shell	80	300	1,000
3	Periwinkle shell	40	680	800
4	Palm kernel shell	77	310	1,000
5	Egg shell	50	710	800

particles experienced glass transition at 380°C and experienced a total weight loss of 80%.

Egg Shell Particles

The thermogravimetric behaviour of the egg shell particles is described by Figure 15. The weight loss curve shows a small peak at 300°C which indicates the giving off of trace amounts of volatile hemicellulose that may be present in the material. The next point of inflection on the curve is an elongated peak between 650 to 780°C which represents the loss of lignin. The thermal disintegration of the particles was negligible between 0 to 300°C as seen on the weight loss curve before proceeding rapidly between 300 to 680°C. The egg shell particles experienced glass transition at a temperature of 710°C before final disintegration at 780°C, experiencing a weight loss of 45 % in the process.

Two distinct processes, namely, the loss of moisture and dehydration of cellulosic and non-cellulosic materials characterize the endothermic influence in the particles, which is evidenced by an accompanying percentage weight loss in each of the particles. This agrees strongly with the findings of Aku *et al.* (2012). From the foregoing, the thermal stability parameters of the particles are summarized into Table 6.

In the course of using the brake pad in real life, it faces some practical problems. One of these is brake fade. This is a phenomenon that describes an instantaneous heating of brake pad that overcomes the friction compound and subjects the brake pad an unusual situation. In comparing the best results of our study (periwinkle shell and egg shell particle reinforcement) with the lens of TGA, the result exhibited by glass transition temperature are 680 and 710°C, respectively, which are

lower than 1,000F at which brake fade is predominant. With the diffraction pattern of the periwinkle shell particles revealing a very orderly arrangement of ions held in place by an unchanging intermolecular force, it matches with the competing asbestos material. Also, with the diffraction pattern of the egg shell particles showing short elongated peaks which transverse the entire diffractogram of the egg shell particles which is typical of a crystalline order, and it favourably competes with asbestos-based brake pad. Furthermore, concerning the ability of egg shell particles and periwinkle shell particles to recover fast from either elevated temperature or moisture, both competes favourably with the asbestos based brake pad. Finally, with the ability of the material is outstanding concerning contact with the drum or rotor, the development is such that the agro-based material does not detach in chunks to initiate pits.

Novelty and Research Significance

There is an upsurge in the usage of agricultural wastes to reinforce polymer composites for automobile brake pad applications. This is accompanied by noteworthy achievement to displace asbestos-based brake pads at low cost. Diverse research has reported that composite performance could be enhanced by understanding and modifying the structural issues concerning the reinforcement. Regrettably, the egg shell, periwinkle shell, coconut shell and palm kernel are important reinforcements in which we know very little about their diffraction patterns, phase identification and thermal stability. The current study offers measurable data regarding diffraction patterns, phase identification and thermal stability of the

aforementioned five reinforcements. As such, it assists the development of agro-based waste composite materials. Diffraction pattern is known from X-ray crystallographic results of the mentioned agro-wastes. The X-ray crystallography was explored to gain insight into the molecular and physical structural of the agro-wastes in crystal form. The case studied is a group of organic compounds consisting of egg shell, periwinkle shell, orange peels, coconut shell and palm kernel shell. In trying to observe the diffraction pattern, two important issues of concern emerge and the first is the angle of diffraction while the second issue is the intensity of the spot. It should be noted that the intensity of the spot that will be created on the concerned surface is directly proportional to the amount of electrons present in that plane. As the powders of the agro-wastes were placed in the X-ray beam, it was possible to observe all the inter-atomic planes of each agro-waste category. The phase identification effort in the paper yielded the benefit of establishing a previously unknown phase and the possibility of envisaging the spatial spread of the phases. The thermal stability has the benefit of to appraise the thermal hazard latent and the materials properties of the five sample categories considered in this work.

Implication for Practice

This research bridges the gap in knowledge on reinforcements for polymer composite fabrication and the practice implications are as follows:

- Composite designers and fabrication experts are responsible to choose reinforcements with substantial structural integrity for brake pads; thermal stability is critical as automobiles involve lives; the safety of which depends on the withholding temperature of brake pad during operation. Materials with thermal integrity (i.e. periwinkle and egg shells), capable to withstand elevated temperatures are recommended to the composite community of composites researchers.

The procedures to determine diffraction pattern, phase identification and thermal stability will assist in knowing the various levels of quantified structural details in material characterization, important for planning on material choices, composite production planning, and for casting. It is further assist composite designers and fabrication experts to plan on the best option in the composite production for the minimization of effort and to optimize resources. It is possible for the composite designers and fabrication experts to simulate the benefits from composite product options before decision making.

- This work exclusively unlocks doors concerning interfaces of researchers, designers and fabricators to reduce reinforcement and composite cost and promote confidence of the customer in the products and company making the products.
- This research reveals the degree to which search for new materials (reinforcements) has been successful and a promise for new ones.

Conclusions

The aim of this research is to offer new knowledge on the structural analysis of a chosen set of agro-wastes based on their attractive properties, including availability, lightweight, among others. The structural analysis was carried out in terms of diffraction pattern examination, thermal stability and phase identification pursuits, for particulate orange peels, coconut shell and egg shell. Data analysis with representation in structural analysis was conducted; bringing together the largely significant waste that causes environmental hazards but converted into wealth creating reinforcements for composite fabrication. The wastes are spread across the society and are always in abundant quantities. Thus this research as well contributes to presenting new knowledge on useful way of converting wastes to wealth. To follow the

main concern, the conclusions drawn from the research are as follows:

- Diffraction pattern: The orange peel, coconut and palm kernel shell particles were found to be largely amorphous with a low level of crystallinity due to the nature of raw materials, while the periwinkle and egg shell particles exhibited a higher degree of crystallinity also as a result of the nature of raw materials.
- Phase Identification: Various elemental compounds were recognized which are expected to supply the expected physico-mechanical strength found in synthesized fillers.
- Thermal stability: The selected agro-waste materials exhibited good thermal stability, with the periwinkle and egg shell particles attaining higher temperatures over the orange peel, coconut and palm kernel shell particles since the thermogravimetric analysis aided in evaluating the quantity of weight variation of the studied materials.

In the future, research should aim at highlighting some developments on these reinforcements. The periwinkle shell and egg shell particles could be distinguished and combined with other secondary reinforcements for further research as they reveal extraordinary thermal stability behavior. Novel theoretical information could also be developed for the five reinforcements through simulation of important features in the thermal analysis, phase identification and diffraction pattern studies. This will create superior insight of the characterization with respect to state-of-the art research on wastes as reinforcements in composite fabrication.

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