PREPARATION OF KERATINOUS PARTICLES FROM CHICKEN FEATHER FIBRES AS POTENTIAL SUBSTITUTE FOR CARBON BLACK REINFORCED NATURAL RUBBER COMPOSITES

Supported by tetfund

B. T. Patrick[1]*, Y. M. Sani[2], M. T. Isa[2] & B. O. Aderemi[2]

[1]Department of Industrial Chemical Process Technology, Nigerian Institute of Leather and Science Technology, Zaria, Kaduna State, Nigeria

[2]Department of Chemical Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

*Corresponding author: silasbukola@yahoo.com

Received: June 21, 2020 **Accepted:** September 13, 2020

Abstract: Several biowastes have been recently researched as possible substitute for carbon black as filler in natural rubber composites. This work shifted from the usual cellulosic waste to a keratinous waste-chicken feather currently posing environmental threats worldwide. Keratinous nanoparticles were prepared via top – bottom approach and validated via Dynamic Light Scattering analysis. The fillers and vulcanizing additives were mixed and compounded using a two roll mill and a compression moulding machine, respectively. The thermal stability and physicomechanical properties: shore A hardness, tensile strength, modulus 100 and elongation at break of natural rubber vulcanizates when filled with chicken feather fibre nanoparticles in comparison with carbon black filler were studied. The filler loadings ranged from 0 to 10 ppH at intervals of 2. From the results, nanoparticles from chicken feather fibres gave superior thermal stability with a residue of 15.55% as against 8.77%, increase in hardness by 6%, enhancement in modulus (M100) by 71% at 10 ppH, higher elongation at break of 49% at 2 ppH and wear percent of 0.3% as against 0.16% at 10 ppH, when compared with carbon black filled rubber vulcanizates.

Keywords: Feather fibres, shore A hardness, thermal stability, rubber vulcanizate

Introduction

Recently, polymers reinforced with eco-friendly biodegradable and low cost agricultural waste are gaining grounds in polymer composite development. Improved properties are also recorded when micro to nano sized fillers are incorporated in polymer matrices.

Natural rubber (NR) is a green biopolymer with high molecular weight of isoprene (2, 4 methyl-1, 3 butadiene) from agricultural source. NR in its virgin state possesses low strength and dimensional instability under thermal and loading conditions making it practically useless. Hence, virgin rubber is usually reinforced and vulcanized in order to meet useful applications. The inherent strength and stability of natural rubber vulcanizates can be enhanced by incorporating a reinforcing phase in order to obtain improved modulus and durability required for structural and engineering applications.

In a bid to replace carbon black which is one of the most dominant yet harmful reinforcing fillers in natural rubber composites, several agricultural wastes have been recently exploited. Carbon black is obtained from the incomplete combustion of heavy petroleum products and is associated with negative environmental (such as global warming) and health (cancer) implications (Verma *et al*., 2012). It is also known to limit the aesthetic design of rubber products due to its characteristic black colour. Alternative rubber reinforcing fillers to carbon black include sugarcane bagasse (Okele *et al*., 2015), carbonized coir and uncarbonized coir (Aguele *et al*., 2014), velvet tamarind seed shell (Okoh *et al*., 2014), maize stalk (Chigondo *et al*., 2013) and bamboo fibre (Onyeagoro, 2012).

Keratinous sources have nevertheless received low attention and exploitation as compared to their cellulosic counterparts. Keratinous fillers among other natural fillers display unique viscoelastic behavior with an initial linear region followed by a plastic region. This makes them capable of absorbing energy and withstanding forces (Wang *et al*., 2016). A few exploited keratinous fillers include cow bone (Oyetunji *et al*., 2018), feather meal (Hergenrother *et al*., 2015) and snail (Igwe and Ejim, 2011).

Feather keratin possesses relatively low density making them attractive in several industries (Ghosh *et al*., 2017; Ghassamieh, 2011). The cysteine moleculues in keratin gives it high strength (Wrześniewska-Tosik and Adamiec, 2007). The twisted microfibrils and unique honeycomb of feather structure yield fibres of high strength and thermal resistance properties (Oladele *et al*., 2018). The flexible nature and high aspect ratio of feathers' fibre provides toughness and tensile strength required for reinforcement in composite development (Uviersherhe *et al*., 2015; Salehuddin *et al*., 2014). The use of chicken feather as a replacement to carbon black in rubber will provide an economic and sustainable use of the agricultural waste (Staron *et al*., 2011).

Hitherto, feather particles have not been reported as reinforcement in natural rubber matrix. Thus, this research focused on the use of keratinous particles obtained from chicken feather fibre as reinforcement in natural rubber composites and studied the effect of their loading ratio on several mechanical and thermal properties in comparison with carbon black reinforced composite prepared under the same conditions. The fillers and vulcanizing agents were masticated with natural rubber using a two roll mill while vulcanization was carried out with a compression moulding machine. Several physicomechanical analyses were carried out and their thermal stabilities were characterized using thermogravimetric analysis (TGA).

Materials and Methods

Materials

Chicken feathers were collected from a slaughter house in Sabon-gari Local Government Area, Zaria, Nigeria. The carbon black (N330) was manufactured by Warri refinery and petrochemical a subsidiary of Nigerian National Petroleum Corporation (NNPC) with particle size distribution of 50 to 500 nm and was used as received. Dry natural rubber crumb, sulphur, trimethylquinolone (TMQ), stearic acid, zinc oxide and mercaptobenzothiazole disulfide (MBTS), were procured from Tony West rubber factory, Lagos, Nigeria. The specifications of the dry rubber were ≤ 1.00% volatile content, ≤ 0.05% dirt content, ≤ 0.6 % ash content, ≤ 0.7 % nitrogen content, minimum of 30 initial plasticity, minimum of 60 plasticity retention index (PRI) and blackish brown in colour.

Development of nanoparticles from chicken feathers

The sourced chicken feather fibres were stripped off their quill, washed and sun dried. They were further subjected to oven drying at 80ºC for 2 h. The conventional top-down approach of manufacturing micro to nanoparticles using a ball mill was employed (Thakur *et al*., 2012). The dried feather fibres milled repeatedly in a Thomas-Wiley laboratory mill through 0.05 mm mesh sieve. The ground particles recovered from this process was further screened through a 125 µm (sieve mesh number 120 according to BS410) sieve mesh and then ball milled at an estimated vessel speed of 300 rpm at ball to particle ratio (BTP) of 1:20 on weight basis with an average porcelain ball diameter of 2 cm for several hours. The particles were subjected to particle size distribution measurement based on the principle of dynamic light scattering (DLS) with the aid of Malvern mastersizer 3000 (Malvern instrument UK) using water as the dispersant at viscosity of 0.8872 Cp and the results shown in Fig. 1.

Compounding and vulcanization of composites

Particles of chicken feather (CF) and carbon black (CB), vulcanizing agents and natural rubber matrix were compounded using a two roll mill, followed by an in-situ moulding and curing in a compression moulding machine. The formulation used was given on Table 1. The compositions of the particles ranged from 0 to 10 ppH with zero standing for the unfilled rubber vulcanizate. The compounded composites were moulded and vulcanized using locally fabricated metallic moulds of appropriate test shape and dimensions. The cure conditions for the sulphur vulcanization were 140ºC for 13 min using compression moulding technique in an 11 tonne hydraulic press.

Table 1: Formulation for reinforced natural rubber composites

Ingredients	Parts per hundred of rubber
NR	100
Zinc oxide	5
MBTS	2
TMQ	1
Stearic acid	2
Sulphur	3
Fillers (carbon black, chicken feather)	0 – 10 (at an interval of 2 ppH)

Physicomechanical and abrasion resistance analyses

Tensile properties (tensile strength, elongation at break, modulus of elasticity)

The tensile strength was conducted and other parameters calculated in accordance to ASTM D412. Tensile tests were carried out at room temperature using universal Instron machine model 3366 with a load cell 1 kN. Pre-moulded dumb bell shaped specimens were used to perform the experiment at a loading speed of 80 mm/min. The maximum breaking stress (tensile strength) (σ_t) was calculated using the equation below;

$$\sigma_t = \frac{F}{b \times d}$$

Where F is the breaking force (N), b is the width (mm) of the sample and d is the thickness (mm) of sample. The effect of varying filler loading and filler type on tensile strength of natural rubber composites is shown in Fig. 2.

The elongation at break was also calculated using the equation below.

Elongation at break =

$$\frac{Final\ length\ at\ break - Initial\ gauge\ length}{Initial\ gauge\ length} \times 100\%$$

The effect of varying filler loading and filler type on elongation at break of natural rubber composites is shown in Fig. 3.

The modulus at 100% elongation was calculated as given in the equation below. Modulus of;

$$\text{Elasticity} = \frac{Maximum\ stress\ at\ break}{Strain\ at\ break}$$

The effect of varying filler loading and filler type on Modulus 100 of natural rubber composites at 100% elongation is shown in Fig. 4.

Shore A hardness

The hardness of the samples was determined with the aid of a Durometer (Instrol Wilson) according to ISO 7619-1. The samples were cut from each of the vulcanized rubber composite already conditioned. The samples were placed on the foot of Durometer's indenter to determine the extent of penetration of indenter into the sample at several points. The indenter of the Durometer was then pressed into the specimen and the depth of the indentation was read from the Durometer. Five locations on every sample were penetrated and the average computed as the hardness in IRHD in order to ensure reliability. A mean of the five indentations were calculated and recorded. The effect of varying filler loading and filler type against the hardness values of natural rubber composites were plotted in Fig. 5.

Wear test

The abrasion loss of the vulcanized rubber composite samples were determined with the aid of rotary drum abrader in terms of volume loss according to ISO 4649 – 2010 (E) standard using a Martindale Abrasion machine. Three abrasion specimens of each sample with thickness 5 mm and diameter 30 mm were prepared with a drill. The samples were removed from a dessicator and weighed before the procedure. Each sample was mounted against the drum of the abrasion testing machine at applied force of 10 N. The abrasive surface of the wear test machine was covered with an abrasive paper of grade P 220. The machine was programmed to run and stop after 100 revolutions at 40 rev/ min. The samples were reweighed at the completion of each run. The initial, w_1 and final weights, w_2 of the samples in triplicate were measured and the mean weight losses calculated according to equation below;

$$W\ \% = \frac{w_2 - w_1}{w_1} \times 100\ \%$$

The effect of varying filler loading and filler type on weight loss of natural rubber composites were plotted as shown in Fig. 6.

Thermo-gravimetric analysis (TGA)

Natural rubber composites reinforced with 10 ppH of treated and untreated fibres were subjected to TGA measurement as against the unfilled composites using TGA 4000, Perkinelmer. An initial weight was taken and heated from 30 to 900ºC at a heating rate of 10ºC/min. The temperature for different percentages of weight loss, temperature at maximum decomposition and residue at 800ºC of all composites samples were determined and the results tabulated on Table 2.

Results and Discussion

Particle size distribution analysis

The exact sizes of particles were difficult to obtain because of the high number of entanglement and complexity at micro to nano-structural level. Nevertheless, peaks and the percentage volume of each size distribution were used to obtain a range as shown in Fig. 1.

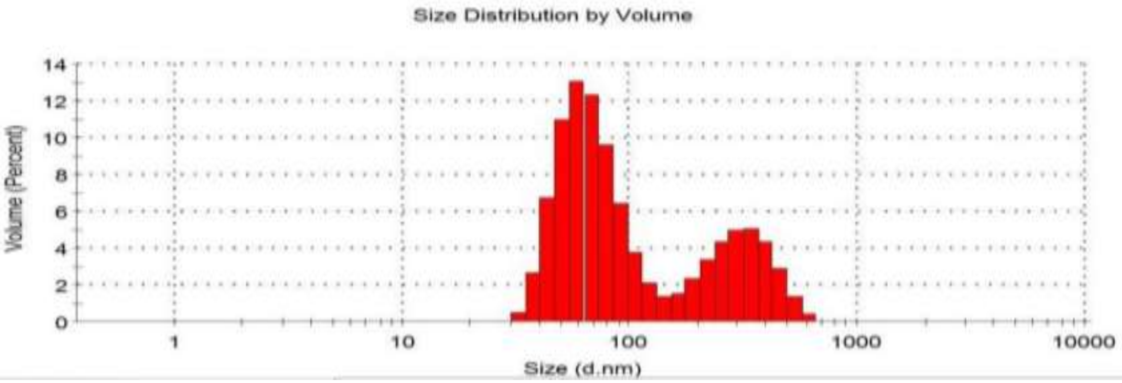

Fig. 1: Particle size distribution of size reduced feather fibres

The particle size of the feather fibre was found to be distributed between 38.4 – 282.9 nm with higher percentage volume of less than 100 nm. This amongst other factors plays an important role in determination of the rubber reinforcement. Generally particles size of less 100 nm is considered to be high reinforcement filler, while particle size of less than 1000 nm is considered to be medium reinforcement filler (Vineetkumar, 2008). Hence, the results of particle size distributions obtained for chicken feather fibre suggest suitability for medium to high reinforcement for rubber matrix.

Tensile Strength

The tensile strength of the composites reinforced with particulate chicken feathers (CF) and carbon black (CB) as presented in Fig. 2, measures the maximum force required to fracture a unit area of the composites under static or quasi-static loading conditions at a defined temperature and strain rate (Oboh *et al*., 2017).

Generally, from the data presented the tensile strength increased with increasing filler loading for both fillers (CF and CB). Improvements from unfilled rubber vulcanizates can be attributed to a high degree of interaction between the rubber chains and the filler particles (Sinclair *et al*., 2017). Nevertheless, carbon black gave slightly higher values. The higher value of tensile strength for carbon black based composites can be attributed to higher surface reactivity of carbon black with polyisoprene molecules which results to covalent bonds when compared with keratinous particle surface. Previous reports by Vineetkumar (2008) have shown that carbon black is capable of bonding both physically and chemically to rubber phase due to its surface reactivity. Nevertheless, particulate chicken feathers (CF) gave an improvement from 1.35 for unfilled rubber to 2.52 MPa at 10 ppH of CF loading and generally close tensile strength values with regards to carbon black (CB) reinforced natural rubber composites at all filler loadings.

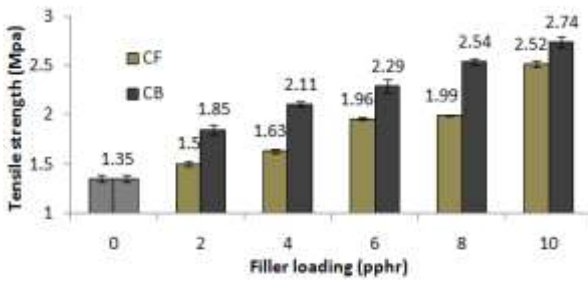

Fig. 2: Tensile strength values for rubber composites reinforced with varying filler loadings of particulate chicken feather and carbon black

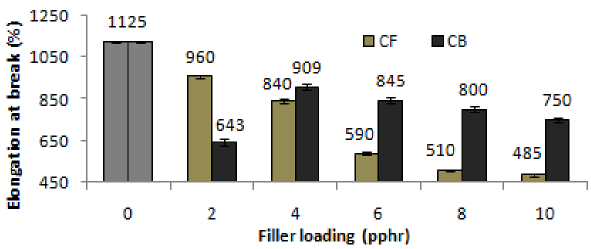

Fig. 3: Elongation at break values for rubber composites reinforced with varying filler loadings of particulate chicken feather and carbon black

Elongation at Break

The elongation at break is the strain or percentage increase in the length of the composites when it breaks. The results of the elongation at break for carbon black (CB) reinforced and particulate chicken feather (CF) reinforced natural rubber composites are shown in Fig. 3.

The percentage elongation at break was observed to have decreased from 960 to 485 % as the particulate chicken feather particles increased from 2 – 10 ppH. Similarly, the percentage elongation at break for carbon black first increased from 643 to 909 % (2 - 4 ppH) and subsequently decreased from 909 to 750 % (4 -10 ppH). A decrease in elongation at break as filler loading increases is explained in terms of adherence of the filler to the rubber polymer matrix leading to the stiffening of the polymer chain and hence resistance to stretch when strain is applied (Ekebafe *et al*., 2010). Particulate chicken feather (CF) reinforced the rubber matrix better than carbon black (CB) at 2 ppH only with regards to elongation at break.

Modulus of elasticity

The modulus of elasticity is a measure of stiffness of an elastic material. Fig. 4 shows the results of modulus at 100% elasticity (M100) of the carbon black (CB) reinforced and particulate chicken feather (CF) reinforced natural rubber composites.

Generally, the filled rubber composites gave higher modulus than the neat rubber (0 ppH). An increase in modulus was attributed to the restriction of the rubber molecular chains mobility when fillers were added. Carbon black filled rubber composites exhibited an irregular trend when their loadings were increased. This behaviour was ascribed to the orientation pattern of the particles within the vulcanized rubber matrix. Whereas, particulate chicken feather filled rubber composites increased in modulus as filler loading increased. This was the same effect reported by Barone and Schmidt, (2005) where feathers was seen to increase the modulus of the composite. Particulate chicken feather (CF) reinforced the rubber matrix better than carbon black (CB) at 8 and 10 ppH only with regards to modulus 100% (M100).

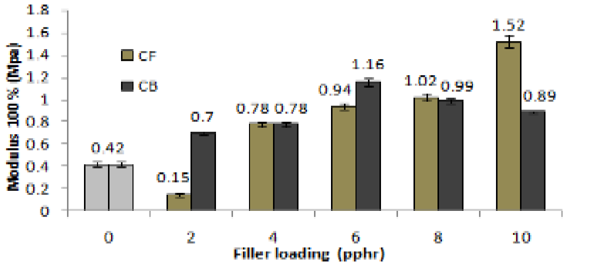

Fig. 4: Modulus 100% values for rubber composites reinforced with varying filler loadings of particulate chicken feather and carbon black

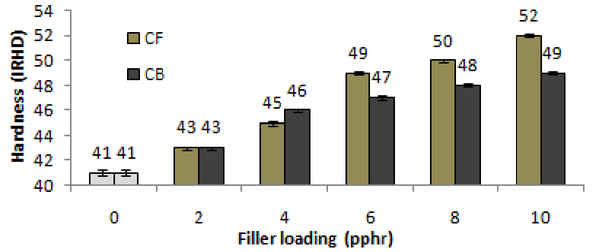

Fig. 5: Hardness values for rubber composites reinforced with varying filler loadings of particulate chicken feather and carbon black

Shore A Hardness

The hardness of rubber measures its resistance to surface indentation. Rubber hardness was measured on Shore A Durometer with calibration scale of 0 to 100 (IRHD). Generally, increase in particulate fillers (reinforcing or non-reinforcing) loading on rubber matrix generally leads to increase in the hardness of the resultant composites due to their ability to reduce rubber chain elasticity (Gumel *et al.*, 2013). The extent of hardness of the filler in a matrix is dependent on its stiffness and volume/ loading (Egwaikhide *et al*., 2007). The results of hardness for carbon black (CB) and particulate chicken feather (CF) reinforced natural rubber composites are shown in Fig. 5.

From Fig. 5, addition of both fillers to the rubber matrix increased its hardness as explained by Gumel *et al*. (2013). The inclusion of particulate fillers into rubber matrix makes the rubber composite to become denser and rigid owing to the reduction of rubber chain elasticity. Increase in hardness results from the hindered rubber chain mobility by the fillers which stiffened the vulcanizates (Motawie *et al*., 2016). However, carbon black yielded harder rubber vulcanizates at 6, 8 and 10 ppH. This was attributed to the stronger bonds due to surface reactivity of carbon in rubber matrix (Vineetkumar, 2008). Particulate chicken feather (CF) reinforced the rubber matrix better than carbon black (CB) at 4ppH only with regards to hardness.

Wear test

The wear is the extent to which a sample is prone to mechanical action such as rubbing, scraping or erosion that gradually removes material from its surface expressed in percentage. The wear percent for carbon black (CB) and particulate chicken feather (CF) reinforced natural rubber composites are shown in Fig. 6.

Wear in natural rubber composite products result in the products' reduction in its usefulness and economic value (Verma *et al*., 2012). From Fig. 6, the wear percent of the neat rubber vulcanizate generally reduced on addition of both fillers. This was attributed to good dispersion and interfacial adhesion of particles in the matrix as explained by Aguele *et al*. (2014). Particulate chicken feather (CF) reinforced the rubber matrix better than carbon black (CB) at 6, 8 and 10 ppH with regards to wear.

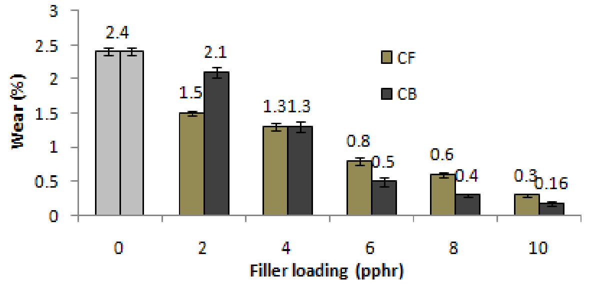

Fig. 6: Wear percent for rubber composites reinforced with varying filler loadings of particulate chicken feather and carbon black

Table 2: TGA and DTG data for unfilled and filled natural rubber nanocomposites

Sample	T5% (ºC)	T50% (ºC)	Thdr (ºC)	Residue (%)
Unfilled NR	200	352	335	3.73
CF (10 ppH)	318	426	395	15.55
CB (10 ppH)	279	328	390	8.77

Thermal gravimetric analysis (TGA)

Thermogravimetric Analysis (TGA) and TGA derivative (DTG) profiles are often useful in providing information with regards to decomposition temperatures and in the assessment of the thermal stability of rubber composites (Aleksandra *et al*., 2014). The TGA and DTG data for carbon black (CB) and particulate chicken feather (CF) reinforced natural rubber composites are shown on Table 2.

The residue left which is the fixed mass at increasing temperature correlates to the inorganic matter present in the nanocomposite. From Table 2, TGA data at 5% (T5%), 50% (T50%) and highest decomposition rate (Thdr) showed higher temperature values for both fillers than neat rubber vulcanizates. This is similar to the case with cellulose particles of all types as reported by Amoke *et al.* (2017). However, particulate chicken feather (CF) gave higher values than carbon black (CB) which corroborates better thermal stability. This was explained by the insulating property of chicken feathers brought about by their inherent hollow structure. Works by Méndez-Hernández *et al.* (2018) and Amieva *et al*. (2015) recorded similar results of better thermal stability for elastomer reinforced with chicken feathers. Also, from the Table 2, the higher residue of 15.55 g for particulate chicken feather (CF) as against 8.77 g for carbon black (CB) reinforced rubber vulcanizates further supports its improvement in thermal stability. Generally, particulate chicken feather (CF) reinforced rubber vulcanizates were thermally more stable than carbon black (CB) reinforced rubber vulcanizates.

Conclusion

Application of feathers as reinforcement contributes to value and waste management of the resource. The top-down method was sufficient for the size reduction of feathers to micro – nanoscale as revealed by Dynamic Light Scattering Analysis. Reducing feather fibres to particles proved to improve several physicomechanical and thermal properties of natural rubber composites and adequately substitute carbon black as filler in rubber vulcanizates. Suggested applications of the developed feather reinforced rubber vulcanizates are in areas where high thermal stability and moderate strength, elongation, hardness and abrasion resistance are required such as in car brake pads and protective footwear.

Recommendations

Surface modification techniques for the particulate feather particles should be further investigated for improved reinforcement abilities to match and possibly outperform carbon black in natural rubber composites. Other properties should also be analyzed to determine other application areas.

Conflict of Interest
Authors have declared that there is no conflict of interest reported in this work.

References

Aguele FO, Madufor CI & Adekunle KF 2014. Comparative study of physical properties of polymer composites reinforced with uncarbonised and carbonised coir. *Open J. Polym. Chem.*, 04(03): 73-82.

Aleksandra ID, Gordana BG, Aleksandra B, Igor G & Luljeta R 2014. Preparation and properties of natural rubber/organomontmorillonite from laboratory samples to bulk materials. *Macedonian J. Chem. Chemical Eng*., 3(4): 123 - 126.

Amieva EJ, Velasco-Santos C, Martínez-Hernández AL, Rivera-Armenta JL, Mendoza- Martínez AM & Castaño VM 2015. Composites from chicken feathers quill and recycled polypropylene. *J. Comp Mat*, 49(3): 275-283.

Amoke A, Ogbobe O, Tenebe GO, Ichetaonye SI & Ayo MD 2017. Physico-mechanical properties and water absorption behavior of natural rubber vulcanizates filled with sawdust. *RRPL*, 8(1): 108.

ASTM D 3184-80 1983. Standard Test Method for Compounding Rubber.

ASTM International 1989. ASTM D 3184-89 Standard Test Method for Rubber Evaluation of Natural Rubber (Natural Rubber). Annual Book of ASTM Standards, ASTM International, 1-3,West Conshohocken, USA.

ASTM International 2006. ASTM D 412 Tensile Properties of Vulcanized Rubber and Thermoplastic Elastomer, Test Method Technote Rubber. Annual Book of ASTM Standards, ASTM International, 1-14, West Conshohocken, USA.

Barone JR &Schmidt WF 2005. Polyethylene reinfosrced with keratin fibres obtained from chicken feathers. *Comp. Sci. Techn.*, 65: 173-181. www.elsevier.com/locate/compscite.

Chigondo F, Shoko P, Nyamunda B, Guyo U and Moyo M 2013. Maize stalk as reinforcement in natural rubber composites. *Int. J. Sci. Techn. Res.*, 2(6): 263-271.

Ekebafe O, Ekebafe O, Ugbesia O & Ewansiha J 2012. Studies on the physico mechanical and equilibrium swelling properties of natural rubber compounds filled with dikanut shell pericarp (*Irviagia gabonensis*) powder. *J. Nat. Sci. Math.*, 5(2): 127-138.

Egwaikhide PA, Akporhonor EE & Okieimen FE 2007. Effect of coconut fibre filler on the cure characteristics physico–mechanical and swelling properties of natural rubber vulcanisates. *Int. J. Phys. Sci*., 2(2): 39-46.

Ghassemieh E 2011. Materials in automotive application, state of the art and prospects. In: *New Trends and Developments in Automotive Industry*, 20: 364 - 394.

Ghosh OSN, Gayathri S, Sudhakara P, Misra SK, Jayaramudu J 2017. *Natural rubber nanoblends: preparation, characterization and applications*. Rubber Nanoblends, Springer International Publishing, Markovic G & Visakh PM (eds) DOI:10.1007/978-3-319-48720-52.

Gumel SM, Adam JL, Ladan M & Habibu S 2013. Effects of treated wood flour on physic-mechanical properties of filled natural rubber. *Chemsearch J.*, 4(1): 42-46.

Hergenrother WL, Shultz LL & Lin CJ 2012. Keratin in Rubber Applications. United States Patent No: US 8,841,361 B2, 2012.

ISO 2010. ISO 7619-1:2010: Rubber, Vulcanized or Thermoplastic - Determination of Indentation Hardness - Part 1: Durometer Method (Shore A hardness).

ISO 2010. ISO 4649:2010 (E): Rubber, Vulcanized or Thermoplastic - Determination of Abrasion Resistance using a Rotating Cylindrical Drum Device.

Igwe IO & Ejim AA 2011. Studies on mechanical and end-use properties of natural rubber filled with snail shell powder. *Mater. Sci. Appl*., 2(7): 801-809.

Méndez-Hernández ML, Rivera-Armenta JL, Sandoval-Arellano Z, Salazar-Cruz BA & Chavez-Cinco MY 2018. Evaluation of styrene content over physical and chemical properties of elastomer/tps-evoh/chicken feather composites. In: *Appl. Mod. Starches*, pp. 1-39. http://dx.doi.org/10.5772/intechopen.72969.

Motawie AM, Mansour NA, Kandile NG, Abd El-Messieh SL, El-Mesallamy SM & Sadek EM 2016, Study on the properties of carbon reinforced unsaturated thermoset polyester resin nanocomposites. *Australian J. Bas. Appl. Sci*., 10(1): 37-47.

Oboh JO, Okafor JO, Kovo AS & Abdulrahman AS 2017. Investigation of eco-friendly cellulosic nanoparticles potential as reinforcement agent in the production of natural rubber composites. *NIJOTECH*, 36(4): 1-10.

Okele I, Mohammed F, Agho B, Marut A & Jekada J 2015. Experimental study on particle size and filler loading reinforcement of sugarcane baggase on natural rubber, *RRPL*, 6(4): 155-160.

Okoh B, Osabohien E & Egboh S 2014. The reinforcing potentials of velvet tamarind seed shell as filler in natural rubber compounds. *Int. J. Biol. Chem. Sci.*, 8(5): 2367 – 2376.

Oladele IO, Okoro AM, Omotoyinbo JA & Khoathane MC 2018. Evaluation of the mechanical properties of chemically modified chicken feather fibres reinforced high density polyethylene composites. *J. Taibah Uni. Sci.*, 12(1): 56-63.

Onyeagoro GN 2012. Characteristics and physico-mechanical properties of carbonized bamboo fibre filled natural rubber vulcanizates. *IJMER*, 2(6): 4683 – 4690.

Oyetunji A, Umunakwe R & Madueke CI 2017. A review on agricultural wastes as fillers for vulcanized natural rubber. *J. Inst. Polym. Eng*., 1(1): 23-34.

Salehuddin SMF, Wahit MU, Kadir MRA, Sulaiman E & Kasim NHA 2014. Mechanical and morphology properties of feather fibre composite for dental post application. *Malaysian J. Anal. Sci.*, 18(2): 368-375.

Sinclair A, Zhou X, Tangpong S, Bajwa DS, Quadir M & Jiang L 2019. High-performance styrene-butadiene rubber nanocomposites reinforced by surface-modified cellulose nanofibres. *ACS Omega*, 4: 13189-13199.

Staron P, Banach M & Kowalski Z 2011. Keratin– origins, properties, application. *CHEMIK*, 5(10): 1019-1026.

Thakur VK, Singha AS & Thakur MK 2012. Green composites from natural fibres: Mechanical and chemical aging properties. *Int. J. Polym. Anal. Character*, 17(6): 401-407.

Uviesherhe OE, Okonkwo UC & Onwuamaeze IP 2015. Optimization of chicken feather fibre reinforced composite with epoxy. *Mater. Sci*., 81: 31974-31977.

Verma R, Tiwari S & Gehllot V 2014. An investigation of abrasive wear in rubber material. *Int. J. Adv. Mech. Eng.*, 4(6): 681-686.

Vineetkumar J 2008. Carbon black filler reinforcement of elastomers. A Thesis submitted to the Department of Materials, University of London for the degree of Doctor of Philosophy, pp. 37-49.

Wang B, Yang W, McKittrick J & Meyers MA 2016. Keratin: Structure, mechanical properties, occurrence in biological organisms and efforts at bioinspiration. *Prog. Mat. Sci.*, 76: 229-318.

Wrześniewska-Tosik K & Adamiec J 2007. Biocomposites with a content of keratin from chicken feathers. *Fibr. & Text.* in Eastern Europe January/March, 15(1): 106-112.