UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 2(3), December (2023), 376-387
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Comparative study on the mechanical properties of fillers-recycled low-density polyethylene for printers and car parts production

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Abstract
Deposition of biomass and waste plastics into the environment generates adverse consequences to humans. This research was investigated to compare the mechanical properties of groundnut shell flour (GSF) and date palm wood flour (DPWF) on recycled low-density polyethylene (RLDP) composite. The DPWF and GSF at 2-30 wt% were injected in RLDP by injection molding method, respectively. The two fibers were analyzed at four mesh sizes from 150-300 µm. The mechanical characteristics of the DPWF and GSF-RLDP composites analyzed were tensile strength (TST), tensile modulus (TMO), elongation (ELO), flexural strength (FST), flexural modulus (FMO) and Izod impact energy (IIME), respectively. Tensile and flexural properties of the composites were determined using tensometer of TUC-100 model and impact strength was studied by impact tester of LS102 DE model. At ultimate mechanical properties of the composites, FTIR and SEM analysis were conducted to reveal composites structural and morphological behaviours. The TST, TMO, FST, FMO, IIME of DPWF-RLDPE and GSF-RLDPE composites improved with addition of DPWF and GSF in RLDPE matrix with the exception of ELO for both properties, respectively. The results indicated that at 250 µm and 30 wt% of fibers in RLDPE matrix, DPWF-RLDPE composite yielded enhanced micro-mechanical characteristics than GSF-RLDPE composite. At this optimum size of the mixture, the TST, TMO, ELO, FST, FMO and IIMO were 9.56 MPa,, 7.55 %, 1.36 GPa, 46.66 MPa, 1.818 GPa, 1.819 GPa and 2 KJ/m for DPWF-LDPE composite, respectively. Furthermore, the GSF-RLDPE composite corresponded to 8, 50 MPa, 12.50 %, 0.94 GPa, 44.45 MPa, 0.84 GPa and 1.21 KJ/m for TST, TMO, ELO, FST, FMO and IIME, respectively. DPWF exhibited explicit mechanical properties than GSF in RLDP matrix for this study as was justified in the result at optimum size of the filler. DPWF exhibits high mechanical properties of composites compared with GSF in RLDP matrix. The mechanical properties of the composites increase with increased filler content. High tensile and flexural properties were obtained at 250 µm and the impact strength was obtained at 300µm. The result of FTIR and SEM for this study justified the results of mechanical properties at optimum size and content of the filler. DPWF possesses good performance when compared with GSF in the production of composites of RLDP for structural and domestic uses. Hence reduces the environmental danger to human through waste disposal. The DPWF-RLDP composite is recommended to be applied in car parts than GSF-RLDP composite at optimum.

Keywords: Ground shell flour, date palm wood flour, fillers-recycled low density polyethylene; comparative study; mechanical properties

1. Introduction

Materials used for the polymer composites are majorly non-metallic compounds called polymer which serves as matrix and enhance its performance by fiber or particulate filler which act as a reinforcement. Filler material may be synthetic or natural (Azeez et al., 2018). Synthetic filler encounters some set back such as: large mass to volume ratio, material and fabrication cost, corrosion of processing machines, etc. Natural fillers are the best option to cushion these flaws ((Dungani et al., 2016; Obasi, 2015; Government et al., 2019 (a-c)). The environment is saturated with polymer waste which constitutes hazard to the human and living organism. In order to reduce this waste in the surroundings and using it for more positive venture, the ideal of collecting it for manufacturing natural filler composite surfaces. This will bring about clean environment, generated resource and improve the economy of the society at large (Atuanya et al., 2014; Government et al., 2013(a-b); Government et al., 2023(a-d)) as well as substitutes for metallic and synthetic fillers (ladadila et al., 2017: Turku et al., 2018). In this latest time, inorganic materials have been abandoning due to their shortcomings (Atuanya et al., 2014; Government et al.,2019 (c-f); Government et al.,, 2016(b); Government and Onukwuli, 2016(a)).

Composites are formed by two or more substance whose characteristic of its end-product is unsimilar to their constituent's substance (Atuanya et al., 2014; Government et al., 2013(b); Laadila et al., 2017). It is comprises of matrices, fillers and/or bonding agent. The matrices are either polymer, ceramic or metals. These help the composite to last long, improve appearance, withstand environment impact and dimension of final products (Azizah et al.,, 2020; Rajak et al., 2019). Fillers are utilized for the manufacturing of polymer composite with improvement in the micro-mechanical behavior of its end-product (Government et al., 2019 (a-f); Government et al., 2020(a); Government et al., 2020(b); Reddy et al., 2013). The types of filler and the species are proportional to the properties of the composites (Atuanya et al., 2014; Bhandari et al., 2013; Fakhrul et al., 2013; Government et al., 2019(a-f)). Generally, composites have the following positive effects: improve strength, flexural and tensile modulus, toughness, cost effective and heat resistance (Atuanya et al., 2014; Government et al., 2013(a-b); Government et al., 2019(a-f); Reddy et al., 2013).

Most research in this present time is aim to source for new fillers which can be used to substitute non-metal compound. Though, these fillers have a major drawback. These are large water absorption, heterogenous mixing due to the nature of polymers molecule, irregular particle size, cannot be applied at high temperature material, etc (Atuanya et al., 2014; Government et al., 2013(a-b)). Examples of natural fillers include oil palm-wood, date-palm-wood, groundnut shell flour, periwinckle shell flour to mention few have been employed for composite production (Government et al., 2023(a-d); Government et al., 2022), but the effectiveness in composites and availability of these fillers remains area of concern which necessitated source for alternative of these natural fillers in composites.

In Nigeria, there are huge deposited of groundnut shell predominantly in the nortern part of nigeria. The reminant of these cash crops can produced tons of fillers for additives for the production of polymer composites (Government et al., 2013(b); Atuanya et al., 2014; Government et al., 2022). Date palm commonly found in nortern part of Nigeria and few in the easter part of the country. The date are mainly consumed thereby ignore its timber which is a major producer of fillers in polymer industries (Government et al., 2021; Government et al., 2013(a); Azeez, 2019; Government et al., 2023(a-d)).

Nothwithstanding, earlier scholars have conducted limited work on the used recycled petrochemicals from plastic depositions in different wood as numerated by Homkhiew et al., (2014), ladadila et al., (2017), Turku et al., (2018) and Azeez (2019), but composite production and its usefulness for commercial purposes depends on most favourable properties like damping, dimensional stability, heat stability, permeability, stiffness, strength, toughness, heat distortion temperature and cost reduction (Turku et al., 2018), which can be determined by the optimum production conditions. In this research, comparing the effect of date palm wood fillers and groundnut shell fillers on the mechanical properties of recycled low-density polyethylene (RLDP) was evaluated and justified with use of FTIR and SEM analysis. This indicates the uniqueness of the composite with the best properties and minimize environment hazard posed by RLDP and fillers as waste for car and printer parts production.

2.0 Material and methods

2.1. Fillers and RLDP used

2.1.1. GSF processing

The groundnut shell (GS) was obtained as a waste from Oba in Nsukka, Nigeria. The GSF was washed with deionized water to eliminate dusty particle, then sun-dried, crushed and grounded. The GSF was sieved with mesh of 150, 212, 250 and 300 µm.

2.1.2. DPWF processing

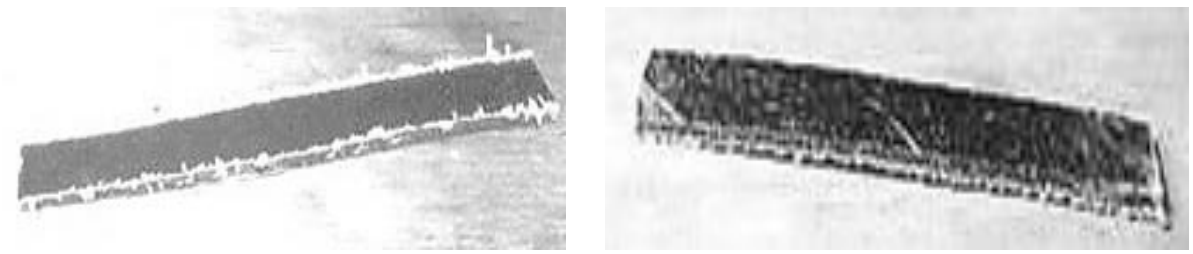
Raw of date palm wood (DPW) fiber was obtained from the Department of agriculture and soil sciences Laboratory vicinity, Nnamdi Azikiwe University, Awka, Nigeria. The wood was sun-dried, crushed and grounded. The DPWF was also sieved using 150, 212, 250 and 300 µm mesh.

2.1.3. Recycled low density polyethylene (RLDP) sourcing

The RLDP was picked in Enugu municipal waste dump. The RLDP erased with clean water, dried in the sun and ground in form of pellets.

2.2. RLDP composites

The fillers were compounded with RLDP. The four meshes are applied for sieving operation. The fillers mixed at 2-30 % by weight of the filler content, respectively. The different composite of both fillers were produced using injection moulding machine and cut into size as presented in Figure 1 (a) and (b) for DPWF-RLDP and GSF-RLDP composite, respectively. The moulding machine has MODEL HUICHON/5SON10/500.1000. No. 6241 1990-6. The composites production was carried at Olikaeze factory at Awada Onitsha Anambra State.



(a) **(b)**

Figure 1: Produced composites of (a) DPWF-RLDP and (b) GSF-RLDP

2.2.1. Testing of Tensile Properties on Specimen

The analysis was done using tensometer with model TUC-100 on the specimens cut into a size of 3 mm x 12.5 mm x 60 mm at a crosshead speed of 5mm/min. The tensile properties of tensile strength, modulus and elongation were determined as outputs of tensile testing.

2.2.2. Testing of Flexural Properties on Specimen

The equipment used is the same as the one used for tensile testing. The sizes used were 3 mm x 40 mm x 140 mm on 3-bending. The test was halt when failure occurred. The equipment electronically printed out the flexural strength and modulus.

2.2.3. Testing of Izod Notch Impact on Specimen

Izod notch impact test was analyzed using impact tester machine (model number LS102 DE). The dimension used was 3 mm × 10 mm×55 mm (ASTM D256). The energy absorbed was calculated after the sample was struck. The Impact and other mechanical testing were all done at Standard Organisation of Nigeria, Emene Enugu.

2.2.4. Statistical analysis

The statistical analysis described by Government et al., (2021), (2022), (2023(a. c, d)) was conducted using Design Expert Version 7.0 with bivariate correlations between RLDP composites of GSF and DPWF. The Pearson's correlation coefficient test was determined with significance of inferior of p-value of 0.05.

2.2.5. FTIR Test

The equipment used was FTIR SYSTEM Spectrum, model number. BX. 100mg of potassium bromide salt and 8mg of each of the composite samples were weighed. The sample was ground uniformly with potassium bromide salt to a mixture. The homogeneous blend of the mixture was placed inside the FTIR spectrometer and processed at a wavelength of 350 – 4000nm. The spectral was displayed at 10 seconds interval. The results were collected to estimate the structural characteristic in the composites. This analysis was examined at University of Ibadan Central Laboratory. Oyo State.

2.2.6. SEM analysis

The sample was charged into the machine. The equipment used was scanning element microscope model PHENOM Pro X. The SEM micrographs were displayed after 5 seconds as an output in the computer. This examination was tested at National Research Institute for Chemical Technology, Zaria, Kaduna State

3.0 Results and Discussions

3.1 Effect of Filler Content on the Properties

3.1.1. Tensile strength

Figure 2 shows the effect of filler content of GSF and DPWF at 150, 212, 250 and 300 µm on tensile strength of the RLDP composites. It can be deduced that the tensile strength of RLDP composites of DPWF are more than that of GSF at different mesh particle size. DPWF decreased the tensile strength of RLDP composites from 9.85 to 9.48 MPa, 9.89 to 951 MPa, 9.95 to 9.56 MPa and 9.88 to 8.5MPa, while that of GSF decreased from 8.56 to 8.20 MPa, 8.85 to 8.4 MPa, 8.92 to 8.5 MPa and 8.59 to 8.25 MPa for mesh particle size of 150, 212, 250 and 300 µm, respectively. DPWF and GSF reduced the tensile strength of the RLDP composites at increased in filler content. This indicates DPWF and GSF are non-reinforcing fillers. This is similar to report in literature (Atuanya et al., 2014; Government et al., 2019(a-f); Government and Onukwuli, 2016(a); Tisserat et al., 2014). It can be seen that there is no significant difference in tensile strength of RLDP composites at increased mesh particle size of the fillers from 150-300 µm as well that of GSF since $p>0.05$, whereas significant reduction in tensile strength of the RLDP composites of GSF by about 15.25 % with $p < 0.05$ was obtained when compared with RLDP composites of DPWF at increased mesh particle size for rag of 150-300 µm. The feeble chemical contact of DPWF and GSF on the plastic is attributed to non-reinforcing property of DPWF and GSF (Atuanya et al., 2014; Government et al., 2019(a-f): Government and Onukwuli, 2016(a); Tisserat et al., 2014). Prior scholarly works have exhibited close results (Atuanya et al., 2014; Government et al., 2019(a-f): Government and Onukwuli, 2016(a); Tisserat et al., 2014). This means reinforcing nature may depend on type of fillers and not mesh particle size.

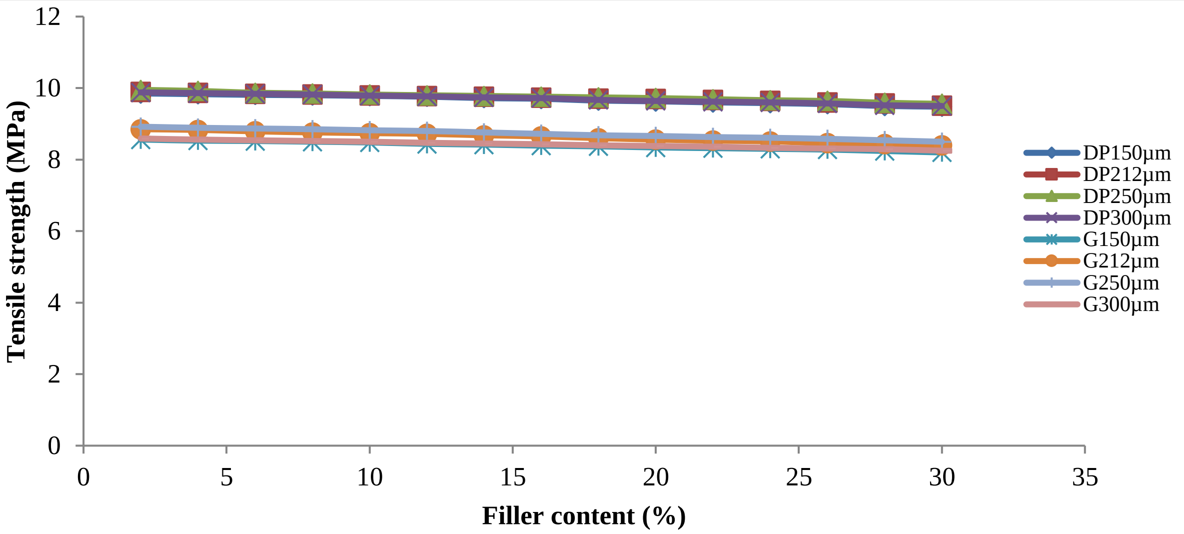


Figure 2: Tensile strength of DPWF-RLDP and GSF-RLDP composites

3.1.2. Tensile elongation

Tensile elongation for RLDP composites of DPWF and GSF at mesh particle size of 150, 212, 250 and 300 µm are shown in Figure 3. Reduction in tensile elongation of RLDP matrix as waste polymeric material with addition of filler content of DPWF and GSF was experienced at different mesh particle size. The attribution for this occurrence is the reduction of ductile nature of RLDP when lignocelluloses were added (Atuanya et al,, 2014). The elongation of DPWF dwindled from 10.50 to 6.70 %, while that of GSF drop off from 14.85 to 12.60 % at 150 µm. At 212 µm, the DPWF reduced from 10.80 to 75.35 %, while that of GSF reduced from 15 to 12.60 %. At 250 µm, DPWF reduced from 10.90 to 7.55 %, while that of GSF shrink from 15.50 to 12.70%. At 300 µm, the DPWF reduced from 10.70 to 6.80 %, while that of GSF reduced from 14.95 to 12.58 %. This toe the path of existing authors {Atuanya et al., 2014; Government et al., 2019(a-f): Government and Onukwuli, 2016(a); Government et al., 2018; Homikliew 2014: Obasi, 2015; Rajak et al., 2019; Government et al., 2023(a-d)).

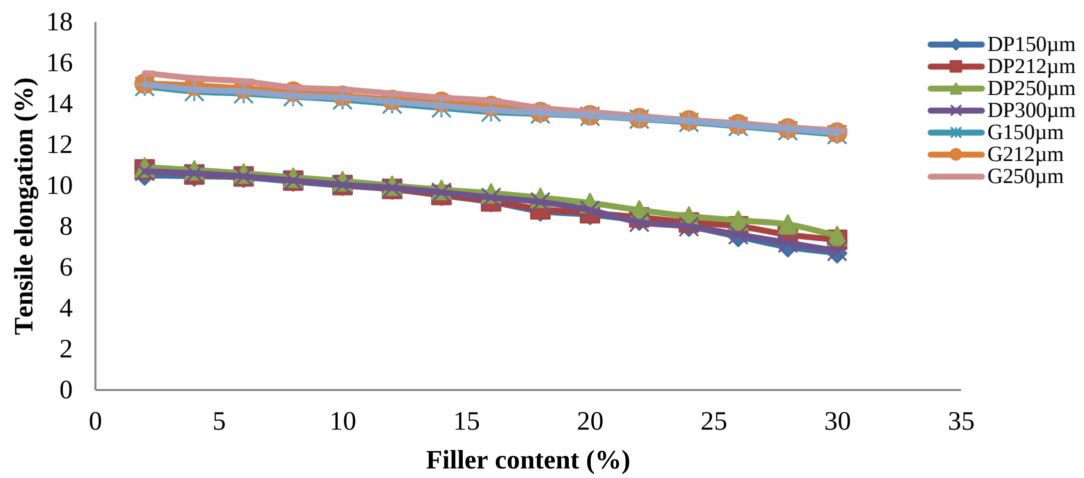
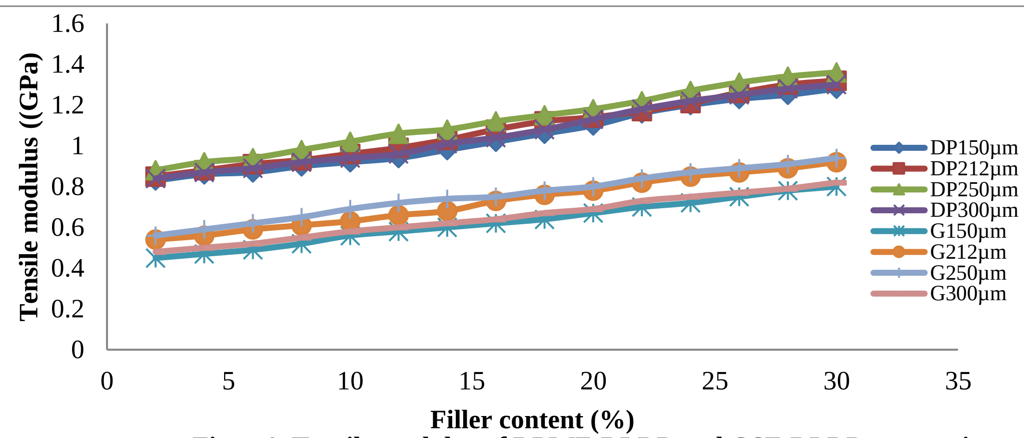


Figure 3: Tensile elongation of DPWF- RLDP and GSF-RLDP composites

3.1.3. Tensile modulus

Figure 4 shows the filler content variation on the tensile modulus of DPWF and GSF at different mesh particle size of 150, 212, 250 and 300 µm. The incorporation of DPWF and GSF found to boost the tensile modulus of RLDP matrix, respectively. The increase in the filler content of increased the tensile modulus of RLDP composites, but with no significant difference in term of mesh particle size of 150, 212, 250 and 300 µm since $p>0.05$. This is as a result of stiffness incurred during addition of organic particulates (Homikliew 2014: Obasi, 2015; Rajak et al., 2019; Government et al., 2023(a-d)). There is significant difference in tensile modulus between the RLDP composites of DPWF and GSF with increased filler content at the same mesh particle size of fillers since $p<0.05$. At 150 µm, the tensile modulus of RLDP composites of DPWF increased from 0.83 to 1.28 GPa, while that of GSF enlarged from 0.45 to 0.80 GPa. At 212 µm, the tensile modulus for RLDP composites of DPWF increased from 0.85 to 1.32 GPa, while that of GSF increased from 0.54 to 0.92 GPa. At 250 µm, the tensile modulus for RLDP composites of DPWF increased from 0.88 to 1.36 GPa, while that of GSF increased from 0.56 to 0.94 GPa. At 300 µm, the tensile modulus for RLDP composites of DPWF increased from 0.84 to 1.30 GPa, while that of GSF increased from 0.48 to 0.82 GPa. This means DPWF makes significant improvement in tensile modulus of RLDP composites compared with GSF irrespective of mesh particle size. The later works highlighted comparable outcome (Atuanya et al., 2014; Turku et al., 2018; Government et al., 2019(a-f): Government and Onukwuli, 2016(a): Government et al., 2018; Homikliew 2014: Obasi, 2015; Rajak et al., 2019; Government et al., 2023(a-d)).



Figur 4: Tensile modulus of DPWF-RLDP and GSF-RLDP composites

3.1.4. Flexural strength

The impact of filler content on the flexural strength of DPWF and GSF at 150, 212, 250 and 300 µm particle sizes was addressed in Figure 5. This described that an augment of flexural strength was heavily influenced by adding natural organic filler. The flexural strength of RLDP matrix was increased by incorporation of DPWF and GSF. Based on mesh particle sizes of DPWF and GSF, there is no significant improvement in flexural strength of the composites. The flexural strength of RLDP composites of DPWF found to be higher significantly than that of GSF ($p<0.05$) at increased filler content of 2-30 %. RLDP composites of DPWF increased the flexural strength from 42.95 to 45.80 MPa, while that of GSF increased from 40.12 to 42.35 MPa at 150 µm. At 212 µm, RLDP composites of DPWF increased the flexural strength from 43.30 to 46.55 MPa, while that of GSF increased from 40.60 to 43.60 MPa. At 250 µm, flexural strength of RLDP composites of DPWF increased from 43.63 to 46.66 MPa, while that of GSF increased from 40.86 to 44.45 MPa. At 300 µm, the DPWF increased the flexural strength of RLDP composites from 43.02 to 45.93 MPa, while that of GSF increased from 40.36 to 43.63 MPa. Researchers have reported close proximity to these results (Atuanya et al., 2014; Government et al., 2019(a-f); Government and Onukwuli, 2016(a); Government et al., 2018; Homikliew 2014: Obasi, 2015; Rajak et al., 22019; Government et al., 2016 (b)).

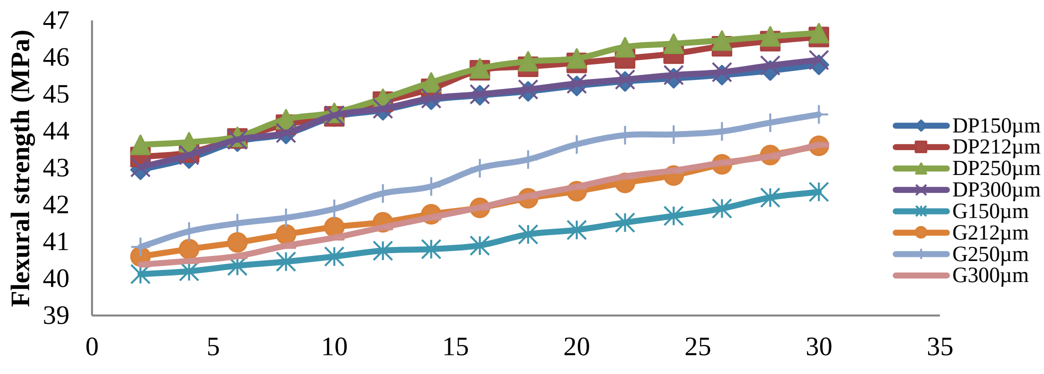


Figure 5: Flexural strength of DPWF-RLDP and GSF-RLDP composites

3.1.5. Flexural modulus

The variance of filler content on the flexural modulus of RLDP composites at particle sizes of 150,212, 250 and 300 µm are shown in Figure 6.

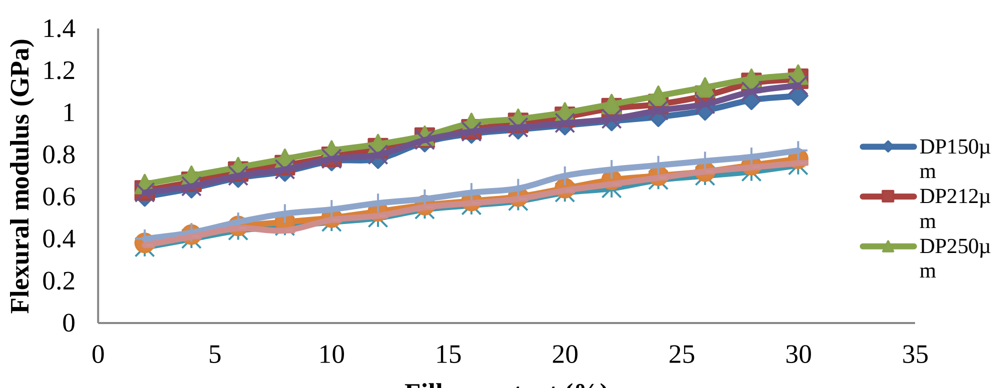


Figure 6: Flexural modulus of DPWF-RLDP and GSF-RLDP composites

This explained that with the increase in filler content, the flexural modulus significantly increased ($p<0.05$), but insignificantly difference at 212, 250 and 300 µm particle sizes due to inferior p-values of 0.05. At 150 µm, the flexural modulus of RLDP composites of DPWF increased from 0.6 to 1.08 GPa, while that of GSF increased from 0.36 to 0.75 GPa. At 212 µm, DPWF increased the flexural modulus of RLDP composites from 0.63 to 1.16 GPa, while that of GSF increased from 0.38 to 0.78 GPa. At 250 µm, flexural modulus of RLDP composites increased from 0.66 to 1.18 GPa, by incorporation of DPWF compared with GSF which increases from 0.40 to 0.82 GPa. At 300 µm, flexural modulus of RLDP composites of DPWF increased from 0.62 to 1.13 GPa, while that of GSF increased from 0.37 to 0.76 GPa. This is in accordance with many researches (Atuanya et al., 2014; Government et al., 2019(a-f); Government and Onukwuli, 2016(a); Government et al., 2018; Homikliew 2014; Obasi, 2015; Rajak et al., 2019; Laadila et al., 2017).

3.1.6. Impact strength

The influence of filler content and mesh particle sizes on the Izod notched impact energy of DPW and GSF are revealed in Figure 7. This depict that the impact energy was significantly increased by injecting fillers (DPWF and GSF) in RLDP matrix at increased filler content of 2-30 % for 212, 250 and 300 µm particle sizes ($p<0.05$) while the increase in impact energy with increased mesh particle sizes was found to be insignificant due to superior p-values of 0.05. The increased in impact energy may be as a result of improved pores formation, composition of filler, and good interaction between the filler and RLDP matrix as reported in literature (Government et al., 2021)/. It can be deduced that DPWF influenced impact energy just as tensile modulus and flexural properties of RLDP composites at increased fillers content. At mesh particle size of 150 µm, the impact energy of RLDP composites of DPWF increased from 1.45 to 1.92 KJ/m, while that of GSF increased from 1.16 to 1.53 KJ/m. At 212 µm, RLDP matrix enhanced impact energy by addition of DPWF from 1.48 to 1.97 KJ/m while that of GSF increased from 1.18 to 1.59 KJ/m. Also, DPWF increased the impact energy of RLDP composites from 1.51 to 2.00 KJ/m, while that of GSF increased from 1.21 to 1.20 KJ/m. also impact energy of RLDP composites increases from 1.56 to 2.06 KJ/m with increased DPWF content from 2-30 %, while that of GSF increased from 1.25 to 1.65 KJ/m at 300 µm. This means that larger force is needed for impact failure as filler weight increases. Generally, DPWF is harder filler than GSF in the RLDP. This supports the results of other research (Atuanya et al., 2014; Government et al., 2019(a-f); Government and Onukwuli, 2016(a); Government et al., 2018; Homikliew 2014; Obasi, 2015; Rajak et al., 2019; Government et al., 2021; Government et al., 2022). This means the use of DPWF-RLDP composites can be efficient and employs in printer parts and automobile applications.

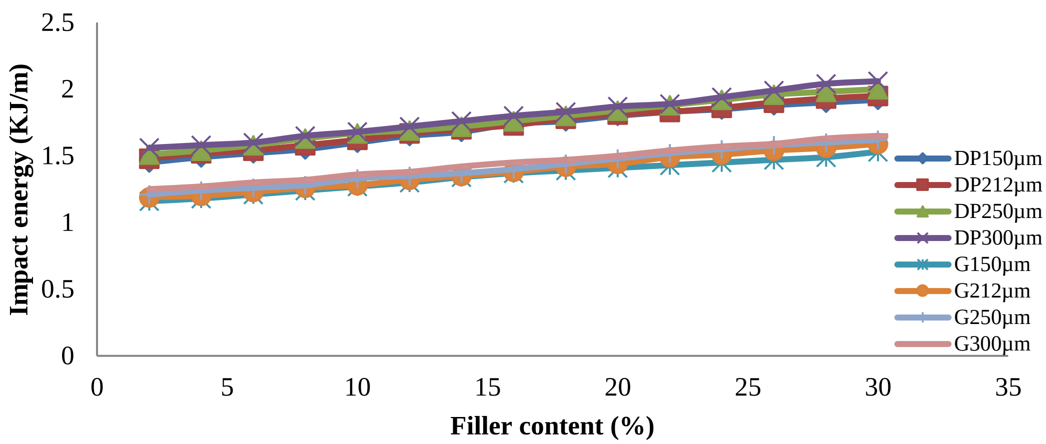


Figure 7: Impact strength of DPWF-RLDP and GSF-RLDP composites

3.2 FTIR of the composite

Figure 8 shows FTIR spectra of RLDP matrix, DPWF-RLDP and GSF-RLDP composites at 30 % filler content for 300 µm. The wave numbers which corroborates the functional groups were obtained in the FTIR spectra diary (Oushabi et al., 2017). There is disappearance of wave numbers which represent the absorption peaks in RLDP matrix as well as variation in transmittance as shown in Figure 8(a) and resulted to formation of composites in Figure 8(b) and Figure 8(c). It was observed that the peak at 3441.42-3440 cm^{-1} confirmed -OH group. The characteristic of the peak at 2931.42cm^{-1} indicated the presence of C-H (alkane). The peak at 2360 cm^{-1} (variable) stretching bond is associated of C°N (nitrile). The peak at 1623.83-1618.13 cm^{-1} (medium) bending bond depicts C-N (amine). The peak at 1472.79-1455.69 $cm-^{1}$ (variable) scissoring and bending bond exposed of C-H (alkane). The peak at 1116.58 cm^{-1} (strong) stretching bond formed of C-O (ester). The peak at 1022.53-675 cm^{-1} (strong) bending bond inferred C=H (alkene). The peak at 600.77 cm^{-1} (broad) bending bond is proportional to C≡H (alkyne). The wave at 500-300 cm^{-1} (strong) bending bond is consigned with C-I (alkyl halide). It was observed that in Figure 8(b) and Figure 8(c), there are changes in position of the function groups in the peaks. There is formation of esters group in DPWF-RLDP composites was not found in the GSF-RLDP composites. This is due to the difference in constituents of date palm and groundnut shell fillers used in composites. Peculiar condition was adopted by previous authors (Oushabi et al., 2017; Ikramullah et al., 2018).

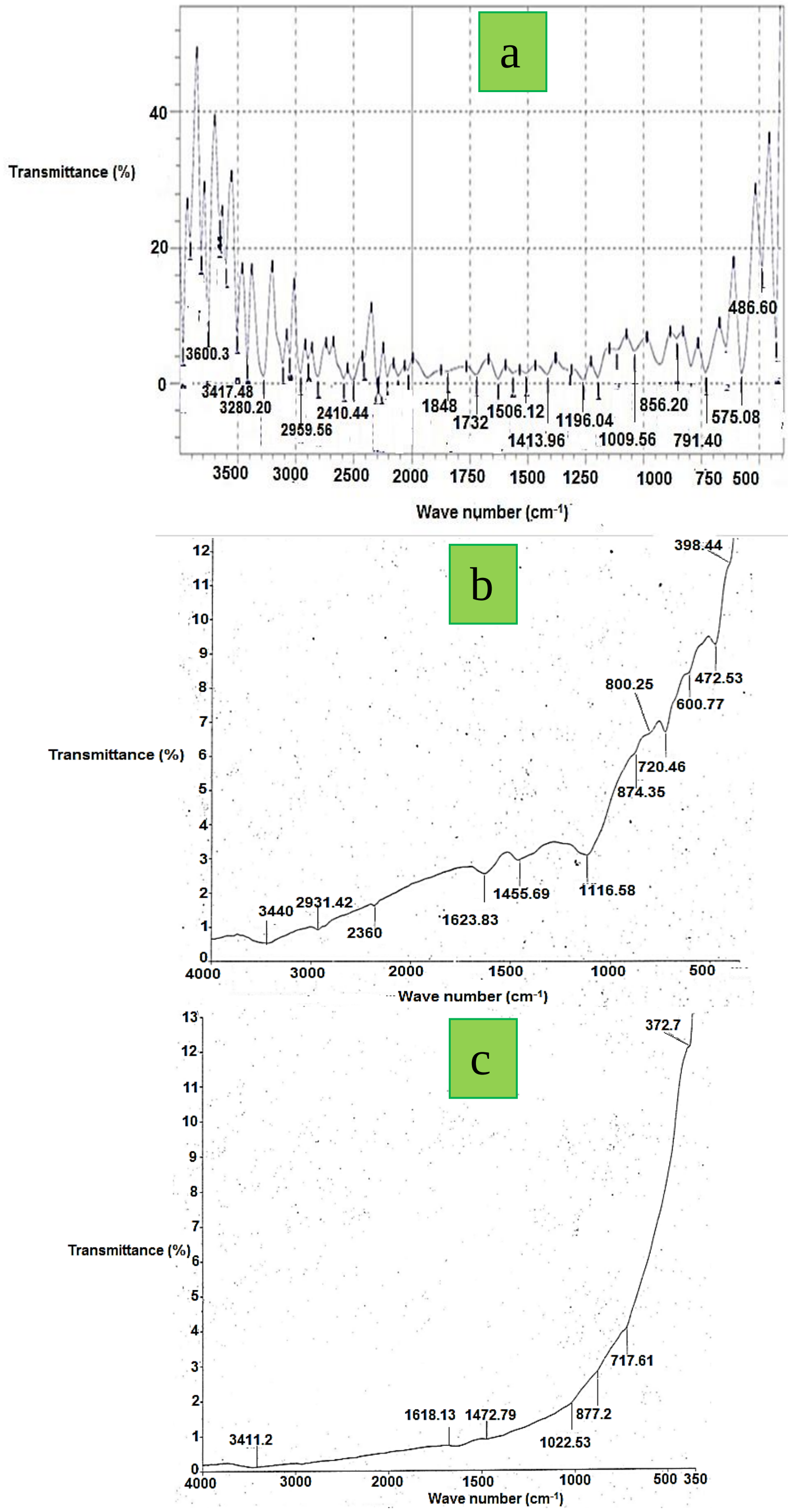


Figure 8: FTIR spectra of (a) RLDP matrix (b) DPWF-RLDP (c) GSF-RLDP composites at 30% filler content.

3.3. SEM of the composite

Figure 9(a) and 9(b) shows the SEM micrographs of the DPWF-RLDP and GSF-RLDP composites, respectively. These micrographs show that the addition of GSF and DPWF to the RLDP matrix results to the filler/polymer morphology, which shows how the fillers are dispersed in the RLDP matrix, respectively, which may be due to poor mixing between the fillers and the matrix. From the micrographs, there are more of the fillers in Figure 9 (a) that did not fill up in the polymer matrix than that of Figure 9(b). From the SEM analysis, the DPWF disperses more in the RLDP matrix which portray an improved property than that of GSF. The defects were indicated with arrows on the SEM micrograph images for both Figure 9(a) and 9(b). Figure 9(b) showed much concentrations of low inter-compatibility between GSF and RLDP matrix. This mighy be as results of low cellulosic strength of the GSF which cteates weak bonding of GSF-RLDP composite. Furthermore, as can be traced in Figure 9(a) by the arrows on micrograph of DPWF-RLDP composite. The observation of the concentration for the compatibility interms of DPWF and RLDP matrrix is averagely minimal. This is due to better strength of the cellusic nature of DPWF in RDPF resin which ultimately beefed up DPWF-RLDP composite properties. Then GSF-RLDP composite. Concurrent trends was noticed in literature (Bhandari et al., 2013; Oushabi et al., 2017; Government et al., 2019(a, c-f): Government and Onukwuli, 2016(a); Government et al., 2018; Homikliew 2014: Obasi, 2015; Rajak et al., 2019).

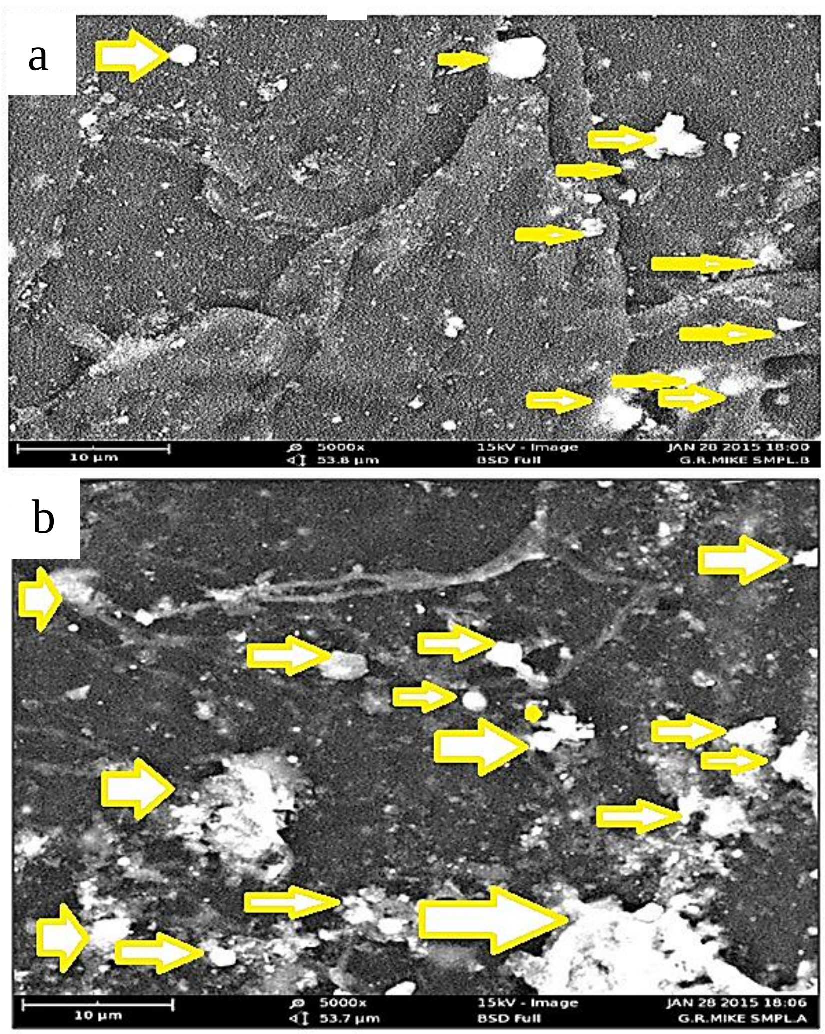


Figure 9: SEM of Composites (a) DPWF-RLDP (b) GSF-RLDP

4.0. Conclusion

In this research, the effectiveness of two different organic fillers (DPWF and GSF) have been investigated on waste plastic (RLDP) for production of composites. The uniqueness of the two composites was determined by characterization of mechanical properties which FTIR and SEM test. The mesh particle sizes of DPWF and GSF were insignificantly influenced mechanical properties of composites while the filler content increased the tensile modulus, flexural properties and impact energy but reduced the tensile strength and elongation. The superiority of performance of RLDP composites of DPWF compared with that of GSF corroborates with FTIR and SEM results. Hence, the favourable properties of RLDP composites of DPWF determined its applications, especially in automobile and printer parts products at optimum process condition.

5.0 Recommendation

The composites produced from this study can be applied as alternative engineering materials for automobile and printer parts components.

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