MANAS Journal of Engineering
ISSN 1694-7398 | e-ISSN 1694-7398

Volume 7 (Issue 2) (2019) Pages 89-93

Mechanical and microstructural characterization of rubber particle reinforced thermoplastic for automobile bumper application

Muideen Adebayo Bodude[1], Theddeus Tochukwu Akano[2,*], Adebayo Felix Owa[3]

[1]Department of Metallurgical and Materials Engineering, University of Lagos, Akoka, Lagos, Nigeria. mbodude@unilag.edu.ng

[2]Department of Systems Engineering, University of Lagos, Akoka, Lagos, Nigeria. takano@unilag.edu.ng, ORCID: 0000-0002-6998-0743

[3]Department of Materials and Metallurgical Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria

ABSTRACT

Thermoplastic elastomer composite produced from low-density polyethylene (LD-PE) mixed with 150 µm pulverised rubber particles in varied proportions (5%, 10%, 15%, 20% and 25%) using stir casting technique was characterized for mechanical properties in relation to the base polyethylene. Tensile, impact, flexural, and hardness tests were conducted to investigate the mechanical properties of the elastomer. The results obtained showed that the reinforcement with up to 20% wt of pulverised rubber particle generated a composite with a higher modulus of elasticity of 374MPa and hardness of 14.06BHN relative to those of the base material which are 227 MPa and 11.48 BHN respectively. However, the bending strength and the impact energy of the generated composite are 40MPa and 19.5 J, which are lower than those of the base material, which are 57 MPa and 20 J. This may be due to insufficient adhesion between the phases of the matrix and reinforcement.

ARTICLE INFO

Research article

Received: 30.10.2019
Accepted: 02.12.2019

Keywords:
Elastomer,
automobile tyres,
mechanical properties,
stir casting,
thermoplastic,
polymeric composite

*Corresponding author

1. Introduction

Polymer modification for improved properties and applications are currently being researched worldwide [1–4] investigated the bonding characteristics of ground rubber (GR) blended with isotactic polypropylene (PP) and discovered that properties comparable with commercial thermoplastic vulcanizates were achieved when creating bonds between the rubber particles and the thermoplastic matrix. Xin *et al.* [5] prepared expanded composites from GR/PP using a single-screw foam extrusion setup and chemical blowing agent. Guo *et al.* [6] prepared and characterised thermoplastic elastomers from scrap rubber powder, and linear low-density polyethylene (PE-LLD) treated with dual compatibiliser consisting of PE-LLD grafted with maleic anhydride, methyl methacrylate and butyl acrylate and epoxidised natural rubber (ENR). Their findings revealed that the mechanical properties, especially elongation at break improved phenomenally after compatibilisation. Grigoryeva *et al.* [7] prepared thermoplastic elastomers based on recycled PE-HD, ethylene-propylene-diene terpolymer (EPDM) and ground tyre rubber (GR) treated with bitumen. The authors concluded that bitumen acts as an effective devulcanizing agent in the GR treatment stage. Li *et al.* [8] synthesised PE-HD/ground rubber powder (GR) composites modified with various elastomers (ethylene-propylene copolymer, EPDM, ethylene-octylene copolymer) and dicumyl peroxide and/or dimethyl silicon oil. The rheological behaviour, dynamic mechanical properties, and morphology observation suggested that an enhanced adhesion between GR and polymer matrix formed in the modified PE-HD/GR composites.

Naskar *et al.* [9] used rubber hydrocarbon of ground rubber tyre (GRT) as a partial substitute for EPDM in a dynamically vulcanised EPDM/acrylic-modified PE-HD blend. The 60:40 rubber/plastic blends were found to behave like a thermoplastic elastomer, and it was observed that 50 wt. % of EPDM can be replaced by GRT without deterioration of properties. Low-density polyethylene (LD-PE) can be used for blending with ground waste rubber as well. Kumar *et al.* [10]

nvestigated TPEs based on ground tyre rubber (GTR, particle size 0.4 - 0.7 mm, untreated or thermomechanically decomposed), LD-PE and fresh rubber (natural rubber, styrene-butadiene rubber, EPDM) prepared with and without dynamic curing via sulfur or peroxide. Recipes containing decomposed GTR and EPDM gave the best performance. This was attributed to the dual compatibiliser effect of EPDM. Nevatia *et al.* [11] prepared thermoplastic elastomeric compositions from reclaimed rubber and scrap LD-PE. The 50:50 rubber-plastic ratio proved to be the best for processability and ultimate elongation.

A branch of waste tyre management is material recycling. Waste rubber is ground (at ambient temperature or cryogenically), and the product has vast application possibilities. It can be used to construct playground, parking lots, or produce railroad sleepers, bank stabilisers, noise barriers etc. A route to a high level of quality is offered by blending rubber powder with thermoplastics to form materials similar to thermoplastic elastomers.

This work is aimed at producing thermoplastic reinforced with rubber obtained from waste automobile tyre with a view to producing elastomer usable for such applications as automobile bumper, cable and wire, jacketing, hydraulic engine mount and head shield where high hardness, high young's modulus and good flexural and impact strengths are required.

2. Materials and methods

2.1. Materials

The low-density polyethylene (LD-PE) pellets used were purchased from a commercial polymer Market in Ojota, Lagos Nigeria on which FTIR test was conducted to ascertain its chemical composition. Grounded Rubber Tyre waste was obtained from a local rubber factory. The rubber waste chips were passed through a conventional high powered, locally fabricated grinding mill. Natural Rubber was also obtained from the same rubber factory. This was also cut into a smaller piece. The compositional analysis of the ground rubber (waste tyre) is presented in Table 1.

2.2. Methods

2.2.1. Sample preparation

Ground rubber powder was sieved using ASTM Standard sieve of 100 BSS to obtain the particle size of 150 µm. The calculated amount of this powder, the natural rubber as well as the polyethylene pellets was weighed and charged in the stir casting machine maintained at 200^{O}C and continuously stirred until the homogeneous melt is obtained. The molten elastomer is then poured in the already prepared wooden mould and allowed to solidify.

Table 1. *Chemical Analysis of Rubber Used for Automobile Tyre [12]*

Ingredient	Composition
Natural rubber	43%w
Synthethic rubber (styrene butadiene) rubber and butadiene rubber)	<22.8%w
Vulcanizing agent (sulphur)	<0.8%w
Accelerators (MBT/TMT)	<0.8%w
Inorganic activators (Calcium/zinc oxide)	<3.3%w
Carbon black	<27%w
Plasticizer(mineral oil)	
Antioxidant and antiozonant	<1.3%w
Other components	<1%

2.2.2. Microstructural analysis

The optical microscopy of the samples was conducted by grinding and polishing the surfaces of the samples followed by observation using an optical microscope focused at a magnification of 200 to reveal the internal structure of the composites. The micrograph is thus obtained by the camera attached to the machine.

2.2.3. Mechanical tests

Three samples each were used for the mechanical tests reported below. The average of the values obtained was however used for the analysis. The resistance of the elastomers samples to indentation and penetration (Hardness test) were measured using Brinell hardness tester. The hardness was indicated by the diameter of the indentation made on the sample by a 10mm ball indenter pressed on the sample by a load of 1000N for 10seconds. The tensile test samples were prepared as a dumbbell test pieces and the testing procedure was carried out in accordance with the ASTM E8 specification. The test sample was held in the grips of Instron 3369M Tensometer and subjected to tensile load until it fractures.

The flexural test was conducted using the 3-point ASTM standard specification method. The maximum stress absorbed to failure by the material was recorded along with other relevant data obtained from the test. The stress at fracture is known as the flexural strength, fracture strength, modulus of rupture, or the bending strength. The Izod impact test was carried out on the notched samples held in a vice while a heavy pendulum, mounted on ball bearings was allowed to strike the samples after swinging from a fixed height. The energy absorbed in breaking the sample is thus indicated on the machine as the impact energy. The impact energy is an indication of the fracture toughness of the material.

2.2.4. Fourier Transform Infrared Spectroscopy (FTIR) test

The functional group of the low-density polyethylene was determined using the FTIR test. This was done to ascertain the quality of the material. An infrared (IR) spectrum, which consists of a plot of stretching frequency (in cm^{-1}) versus intensity (as measured by percentage transmittance) was obtained from this test. The peaks in IR spectrum reveal the functional groups present in the molecule.

3. Results and discussion

The absorbance spectrum indicated in Fig. 1 corresponds to Isocyanate functional group. This confirmed the quality of the low-density polyethylene (LD-PE) used as a matrix for this study.

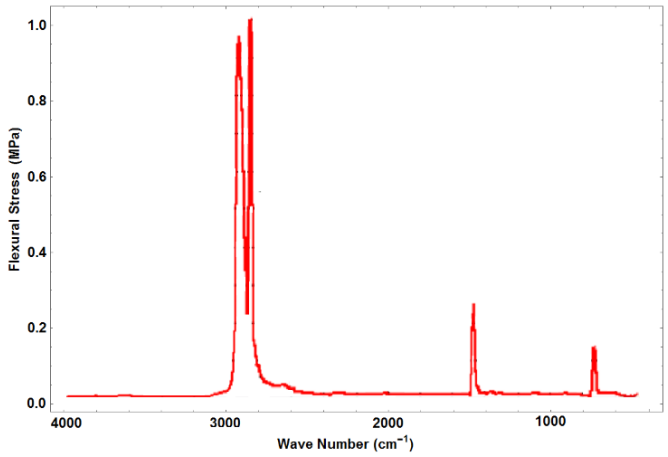
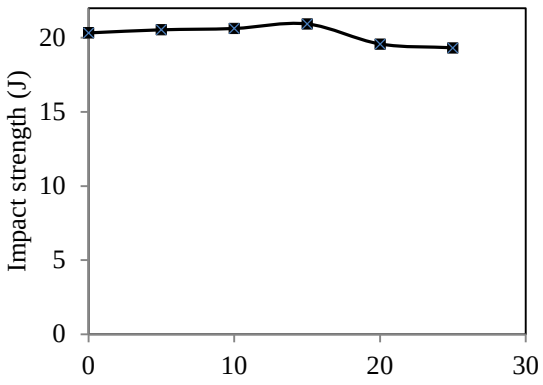
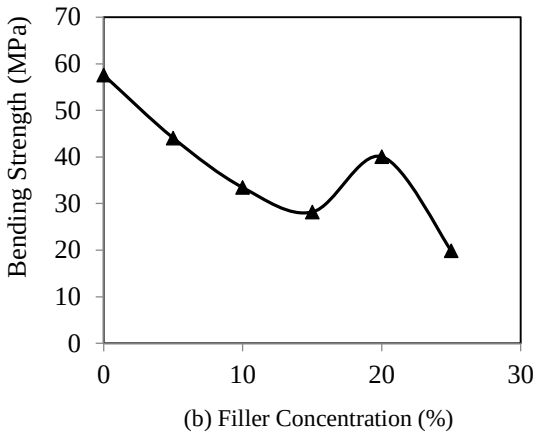


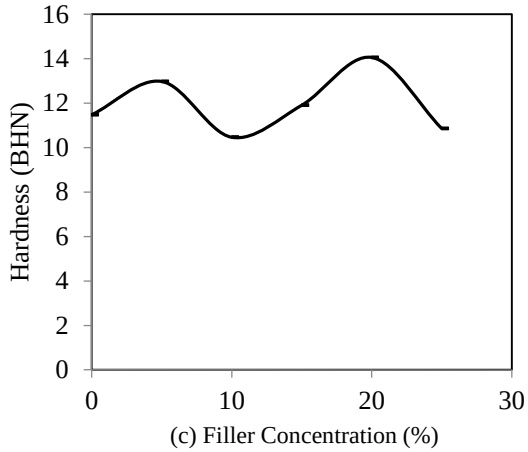
Figure 1. *FTIR of Polyethylene*



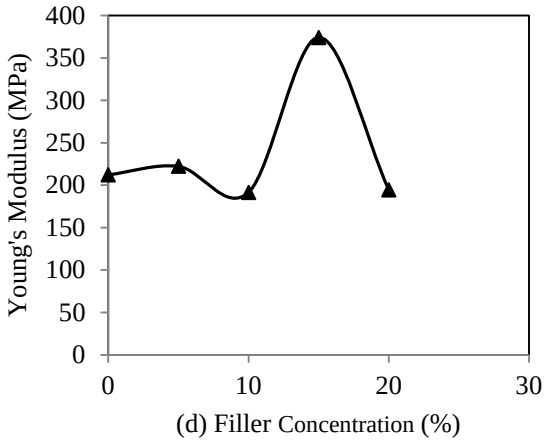
(a) Filler Concentration (%)



(b) Filler Concentration (%)



(c) Filler Concentration (%)



(d) Filler Concentration (%)

Figure 2. *Mechanical properties variation with filler concentration*

The plots of filler concentration against the mechanical property parameters are shown in Figs. 2(a)-(d). From Fig. 2(a), the impact strengths of the composites increase slightly with an increase in filler concentration to 20.94J at 15% filler and drop subsequently upon an increase in filler concentration. While Fig. 2(b) shows the plots of bending strength of the composite against filler concentration. This figure shows that the bending strength of the elastomer fell

between 0 - 5% filler concentration and continued with the trend up to 15% but peaked at 20% and decreased again at 25% rubber particle addition. This unstable behaviour may be attributed to the fact that as the amount of reinforcement increases, there is a reduction in the total surface area available for matrix-filler interaction. Fig. 2(c) indicates the graph of the composites hardness versus the filler concentration. From this plot, the base material has hardness value of 11.48BHN and this slight increase to 12.98BHN when 5% of ground rubber filler was added and it dropped to 10.47 with 10% filler. However, it attained the highest of 14.06BHN when 20% filler was added. Fig. 2(c) shows the young's modulus of elasticity of the composite against the filler concentration. The modulus follows the same trend as the bending strength. However, both the young's modulus and the hardness values increased while the bending and impact strengths reduced with increasing rubber particles filler addition. This shows the dependence of all these parameters on the percentage proportion of the filler. Fig. 3 shows the flexural stress-strain behaviours of all the samples. The Figure shows that all the samples reinforced (composites) have better flexural strength than the control sample (LD-PE). While the plots of filler concentrations against flexural test results are shown in Figs. 4 and 5. From these Figures sample with 5% filler addition has the highest flexural strength of 44.06MPa, while the sample with 20% filler addition exhibited significantly high flexural strength (40.07MPa) even though these values are lower than that of LD-PE which is 57.58MPa.

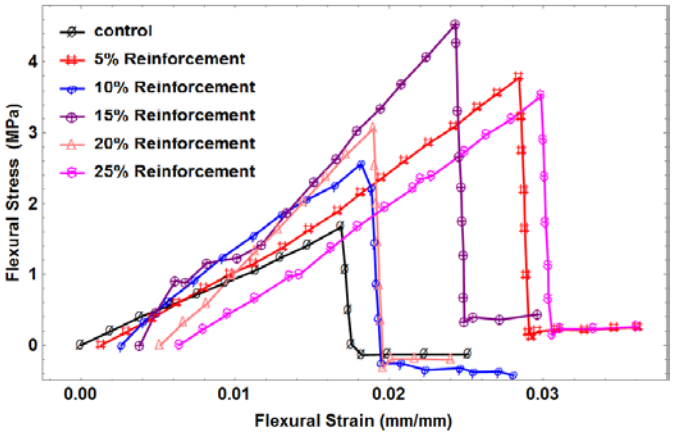


Figure 3. *Flexural stress-strain of the rubber particle reinforced elastomer*

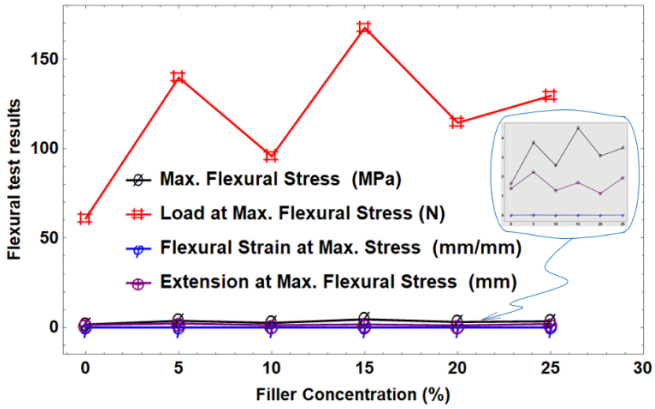


Figure 4. *Filler Concentration against various flexural test results*

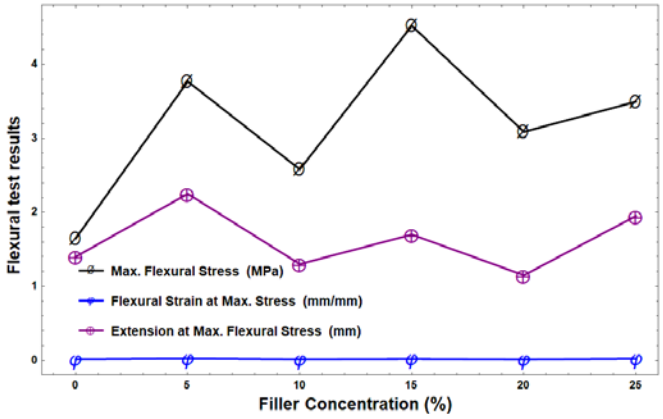
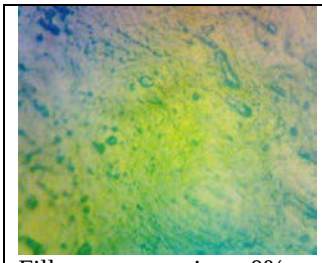
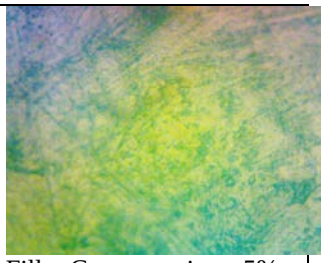


Figure 5. *Filler Concentration against various flexural test results from Fig.4*

The microstructures of the samples from 0 - 25% filler additions are shown in Fig. 6. The filler appears as additional black particles which already exist in the LD-PE. It can be seen that the volume of the particle increases with percent filler addition and their dispersion within the matrix is generally uniform. The rubbers are well agglomorated and evenly distributed within the matrix as displayed in Fig.6.



Filler concentration - 0%



Filler Concentration - 5%

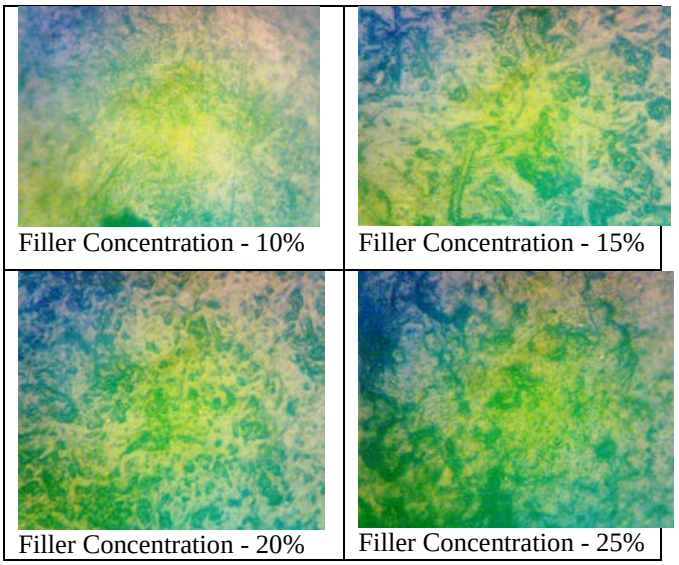


Figure 6. *Optical micrographs of LD-PE thermoplastic elastomer*

4. Conclusion

It was noticed that the least hardness value of 10.47 BHN was obtained in the composite with 10% ground rubber particle addition while the highest hardness value of 14.06 BHN was obtained in composite with 20% ground rubber particle addition.The above behavior may be due to the fact that at 20% filler addition the microstructure comprises of highly homogeneous mixture of the rubber particle and the matrices. The filler is evenly distributed in the structure as shown in Fig. 5. The highest young's modulus value of 374 MPa was obtained in composite with 20% filler addition. The highest impact energy of 20.94 J was obtained in composite with 15% rubber filler concentration. It was also observed that composite with 5% rubber particle addition showed the highest flexural strength of 44.06 MPa before shattering relative to other composite samples.

Nomenclature

LD-PE	Low density polyethylene
PE-LLD	Linear low-density polyethylene
PE-HD	High density polyethylene
GRT	Ground rubber tire
FTIR	Fourier transform Infrared spectroscopy
EPDM	Ethylene propylene-diene terpolymer
MPa	Mega Pascal
J	Joule
ENR	Epoxidized natural rubber
GR	Ground rubber
PP	Polypropylene

References

[1]. Egodage SM, Harper JF, Walpalage S. "The development of rubber-thermoplastic blends from ground tyre rubber and waste polypropylene", J Natl Sci Found Sri Lanka (2009), 37.

[2]. Hrdlicka Z, Kuta A, Hajek J. "Thermoplastic elastomer blends based on waste rubber and low-density polyethylene", Polimery, 55, (2010), 832–8.

[3]. Michael H, Scholz H, Mennig G. "Blends from recycled rubber and thermoplastics", Kautschuk Gummi Kunststoffe, 52, (1999), 510–3.

[4]. Mennig G, Michael H, Rzymski WM, Scholz H. "Thermoplastic elastomers from polypropylene-powdered rubber scrap blends", Polimery, 42, (1997), 491–3.

[5]. Zhang ZX, Zhang SL, Kim JK. "Evaluation of mechanical, morphological and thermal properties of waste rubber tire powder/LLDPE blends", E-Polymers (2008), 8.

[6]. Guo B, Cao Y, Jia D, Qiu Q. "Thermoplastic Elastomers .Derived from Scrap Rubber Powder/LLDPE Blend with LLDPE-graft-(Epoxidized Natural Rubber) Dual Compatibilizer", Macromol Mater Eng, 7, (2004), 289-360.

[7]. Tolstov A, Grigoryeva O, Fainleib A, Danilenko I, Spanoudaki A, Pissis P, et al. Reactive Compatibilization of Polyethylene/Ground Tire Rubber Inhomogeneous Blends via Interactions of Pre-Functionalized Polymers in Interface. Macromol. Symp., vol. 254, Wiley Online Library; (2007), 226–32.

[8]. Li Y, Zhang Y, Zhang Y. "Mechanical properties of high-density polyethylene/scrap rubber powder composites modified with ethylene–propylene–diene terpolymer, dicumyl peroxide, and silicone oil", J Appl Polym Sci, 88, (2003), 2020–7.

[9]. Naskar AK, De SK, Bhowmick AK. "Thermoplastic elastomeric composition based on maleic anhydride–grafted ground rubber tire", J Appl Polym Sci, 84, (2002), 370–8.

[10]. Kumar CR, Fuhrmann I, Karger-Kocsis J. "LDPE-based thermoplastic elastomers containing ground tire rubber with and without dynamic curing", Polym Degrad Stab, 76, (2002), 137–44.

[11]. Nevatia P, Banerjee TS, Dutta B, Jha A, Naskar AK, Bhowmick AK. "Thermoplastic elastomers from reclaimed rubber and waste plastics", J Appl Polym Sci., 83, (2002), 2035–42.

[12]. Evans A, Evans R. "The composition of a tyre: typical components". Waste Resour Action Program, (2006), 5.