Nigerian Journal of Engineering, Vol. 29, No. 1, April 2022, ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Effect of Fibre Loading on the Mechanical Properties of Waste Newspaper Particulate Reinforced Unsaturated Polyester Composite

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Research Article

Abstract

This paper presents the usage of waste newspaper particulate (WNP) as a source of reinforcement in polymer composite production. The surface of the WNP was modified using alkaline (NaOH) and silane [3-(trimethoxy silyl) propyl methacrylate] treatment. Different weight percentages of WNP were compounded with polyester. Tensile, flexural, impact and hardness test were performed to obtain the mechanical properties of the compounded composite material. The results obtained for Tensile Strength (TS) and Tensile Modulus (TM), impact test and hardness values showed an increase as the percentage of the waste newspaper particulate reinforcement increased. An increase of 29.45% for TS was observed, 34.95% for TM and 49.21% for impact energy. However, the flexural strength was observed to decrease as filler loading was increased with the maximum value of 57.29MPa at 5wt%.

Keywords

Filler loading; Flexural strength; Hardness value; Impact strength; tensile strength; Waste Newspaper Particulate (WNP)

Article History

Received: – December, 2020
Reviewed: – June, 2021
Accepted: – February, 2022
Published: – April, 2022

1. Introduction

Researchers have been working to produce an environmentally friendly composite that uses natural fibres instead of synthetic fibres as a reinforcement material, in response to growing environmental concerns. In recent years the use of natural plant based cellulosic fibres as reinforcement material in polymer matrix composites (PMC) has created great attention among researcher to produce eco-friendly low cost engineering materials (Das, 2017 and Sastra, *et al.*, 2006). A great deal of interest has been generated in the use of wood fibers as reinforcing fillers in thermoplastic composites. The low densities of lignocellulosic fibers coupled with their low cost makes these fibers potentially attractive for non-structural composite applications. Due to their availability, low cost, low density and renewability, lignocellulosic fibres finds more application amongst other types of natural fibres. Newspapers are made from processed short length cellulose fibres that are mainly sourced from waste paper (Singha & Thakur, 2008). Over 400 million tons of paper are produced annually and this amount is always increasing due to increase in industrialization and urbanization giving rise to increase in population (Shafiur Rahman, *et al.*, 2015). Disposing of the massive amount of paper generated as solid trash is a difficult task. Recycling and incineration were the most common method of managing the amount of wastepaper generated which also come with the challenge of cost and air pollution (Dhokhikah & Trihadiningrum, 2012). The use of paper as reinforcement in various forms in polymer composites helps to better manage the amount of waste paper generated. This sparked the interest in using paper as a reinforcement in polymer composite from a variety of perspectives. Sanadi, *et al.*, (1994) Recycled newspaper fibres as reinforcing fillers in polypropylene thermoplastics to determine the tensile and impact properties of the composite. An improvement from 34.1 MPa to 57 MPa and 112 J/m to 212 J/m in tensile and Izod impact strength was reported. Kalpana, *et al.*, (2009) prepared a carbon-carbon composite electrod material for supercapacitors by KOH activation of waste newspaper. The cyclic voltammetry results reveal a maximum specific capacitance of 180 Fg^{-1} at a $2mVs^{-1}$ scan rate which showed a development interms of using waste paper into a valuable energy storage material. Madani, *et al.*, (2004) researched on the effect of incorporating untreated and treated newsprint in the rubber matrix on the swelling, electrical and mechanical properties, as well as gamma and neutron-shielding power. The study led to conclusion that composite samples containing 6% wax and 54% newspaper or 18% wax and 42% modified old newsprint paper has the higher behavior to g-irradiation dose. The incorporation of modified waste paper into the rubber matrix increases the conductivity and enhances the mechanical properties of produced composites.

Ashori & Sheshmani, (2010) researched on the hybrid composite material made from the combination of recycled newspaper fibre (RNF) and paper wood flour (PWF). Recycled polyproplene (RPP) was used as matrix and maleated polyproplene (MAPP) as coupling agent by injection mould. The research showed composite with highest percentage of PWF to have lower percentage of water absorption capacity and thickness swelling among the hybrids which was attributed to their low holocellulose and high lignin content compared to

RNF. Also, the presence of coupling agent improved the qaulity of adhension between polymer matrix and cellulose material.
Alamri & Low, (2012) studied the mechanical properties and water absorption behaviour of recycled cellulose fibre (RCF) using epoxy matrix. They fabricated the composites by varying the fibre loadings at 19, 28, 40 and 46wt%. Mechanical properties were found to increases as the fibre content increased. Aslo, the stress-strain curve of the study showed the failure mode of the RCF epoxy composite to consist of flexural anf shear failure modes. They observed energy dispersion to increase in the composite with higher percentage of fibre content.
Sangrutsame, *et al.*, (2012) investigated on the potential of utilizing recycled waste paper to manufacture local building components of low cost. Results showed addition of re-pulped waste paper to reduce thermal conductivity and bulk density of cement composite. Das, *et al.*, (2015) prepared a low cost composite material using waste newspaper and polyester resin. A tensile strength of 70MPa and 6GPa modulus was observed by reinforcing polyester with 48% (w/w) in fibre direction while 19MPa tensile strength and 2.41GPa modulus was observed in the cross direction.
This research is focused on characterizing waste newspaper as a reinforcement in polymer composite. The aim of the research is to determine the tensile, flexural, hardness and impact properties of the developed composite.

2. Material and Methods

2.1 Materials

Unsaturated polyester was purchase from West Palm Beach Florida, USA. Cobalt Naphthenate was used as hardener while Methyl Ethyl Ketone Peroxide was used as catalyst. Waste Newspapers (WN) were collected from vendors around Zaria, Nigeria and cut into square sizes of average length of size as 40 mm, soaked in water for 48 hours then grinded into paste. The absorbed water in the grinded paper waste drained, after which the paper paste was sun dried and made ready for surface treatment. 5% concentration of NaOH solution was prepared. The grinded and water-drained WN was soaked and thoroughly mixed in the NaOH solution for effective alkaline treatment of the particulate surfaces. The aqueous sodium hydroxide enhances the ionization of the hydroxyl group to the alkoxide. 3-(Trimethoxy silyl) propyl methacrylate was diluted into 1% concentration by volume and used as a coupling agent saline treatment. The dried-treated paper particulates were then grinded and seized using a sieve with 700µm average size to obtain the fibres in particulate form.

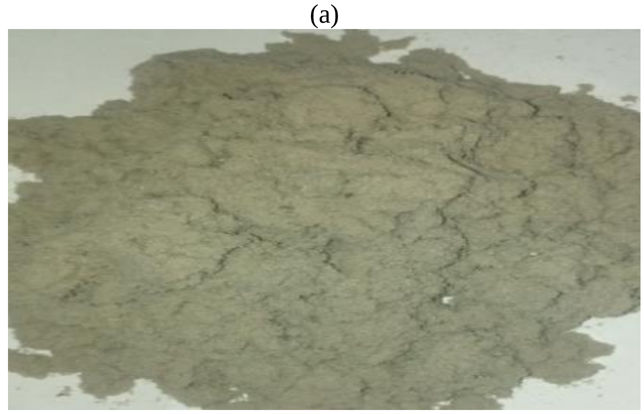
2.2 Composite Fabrication

100ml of the unsaturated polyester, 1.5ml of catalyst (cobalt napthanate) and hardener (methyl ethyl ketone peroxide) were respectively added and stirred for 5minutes. The treated waste newspaper particulate particulates (WNPP) were added into the mixture by weight percentage and manually mixed for 10minutes. The composite mixture was transferred into a jelly coated mould and allowed to solidify for an average time of 30minutes before taken out of the mold.

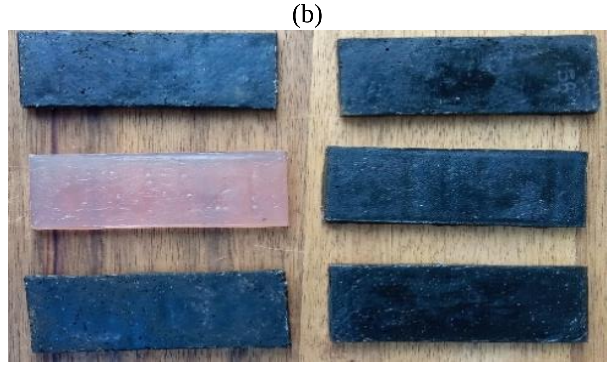
2.3 Composite Fabrication

The newspaper was grinded into particulate form and surface treated. Alkaline treatment was done using of 5% concentration of NaOH and silane treatment with 1% volume concentration of 3-(Trimethoxysilyl) propyl methacrylate. The catalyst and hardener were added into the polyester resin in a ratio of 98:1:1 and thoroughly mixed. Treated fibres based on calculated weight percentage were added into the mixture of the resin, hardener and catalyst, then compounded with a manual mixer for about 10 minutes. The mixed blend was then cast into a designed mold based on ASTM specifications of tensile, flexural, impact and hardness. The surfaces of the mold were lubricated with jelly for easy removal of the composite after curing. Casted composites were allowed to cure under ambient conditions for 72 hours before been tested for different mechanical properties.

(a)



(b)



(c)

Figure 1: (a) Untreated Waste Newspaper, (b) treated waste newspaper particulates, and (c) compounded composite samples.

3. Testing

3.1 Fourier Transforms Infrared Spectroscopy (FTIR)

The Fourier transform infrared spectroscopy (FTIR) analysis of the treated waste newspaper fibre was carried out using FTIR analyzer (Agilent CARY 630) over a wavelength of 600 to 4000cm-1 using the KBr dics sample preparation method at Multi-User laboratory of Ahmadu Bello University, Zaria.

3.2 Tensile and Flexural strength

The tensile test samples for the determination of the tensile behavior of the WNPRC were prepared according ASTM D638. Five samples each for the different fibre loading composition were casted to a size of 35mm gauge length and 5mm thickness and tested on a Monsanto Tensometer Motor Drive machine with a cross head speed-7.5mm/min, serial No of 4612 and a load capacity of 20KN at Ahmadu Bello University, Zaria. The average of the five samples in terms of tensile strength, modulus, extension and strain were calculated in which the strength and modulus were reported in table 1. The specimens were broken between the guage length and some of the images were shown in plate 1.

3.3 Flexural strength

Three point bending test was carried on neat polyester and composite samples developed using ENPAC Universal Testing Machine (Cat.Nr.261) with a 100KN load capacity in accordance with ASTM D790 (2014) standard. Five samples were machined of dimensions of 5mm x 40mm x 100mm. Load and deflections of the specimen at failure were recorded and equations (1) and (2) were used to determine the flexural strength and flexural modulus of the material.

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

$$\text{Flexural Modulus (FM)} = \frac{PL^3}{4bd^2D} \quad (2)$$

Where σ_f is the Flexural strength in (MPa)
P = maximum force at failure (KN)
d = height of the beam (mm)
L = length of the beam (mm)
D = Deflection of the beam (mm)

3.4 Charpy Impact Energy

Five samples each for the different composition of fibre loading were produced in accordance with ASTM D7136(2014) standard of dimensions 90mm x 10mm x 10mm. The samples were notched with a notch angle of 45^o and depth of 2mm ± 0.5mm. The charpy impact test was done by mounting the composite sample on the machine with the notched side of the sample facing the point of contact of the sample and the pendulum hammer of the machine when released. Charpy Impact Testing machine (Cat.Nr.412) was used with a maximum load capacity of 25J.

3.5 Hardness Test

VICKERS Hardness Testing Machine [MVI-PC, Model: 8187.5 LKV (B)] was employed in the determination of the hardness property of the composite material under ambient conditions of pressure, humidity and temperature. The hardness scale of F was used. The indenter was a steel ball of (1.6mm) diameter. The samples were subjected to a preload and total load of 10kg and 60kg respectively.

3.6 Scanning Electron Microscopy (SEM)

The micro structure of the produced composite was observed under a SEM. Composite sample of 10mm-by-10mm dimension (with different percentage reinforcement) were developed to examine the morphology and fibre-matrix interaction. Phenom ProX (PhenomWorld, SN: MVE01570775, Model No: 800-07334.) SEM machine was used in the observation.

4. Results and Discussion

4.1 Fourier transforms infrared spectroscopy analysis of Newspaper

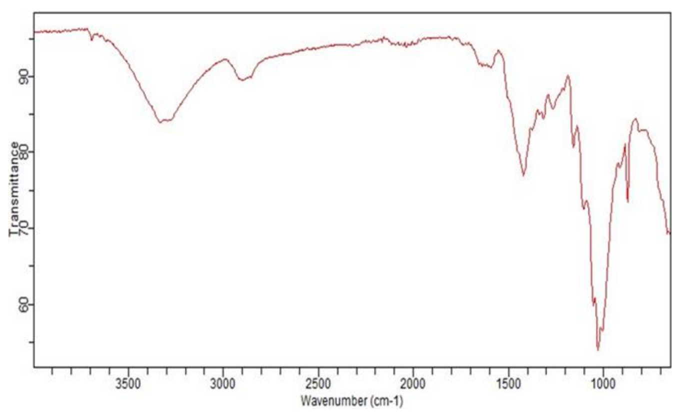


Figure 2: Fourier transform infrared spectroscopy (FTIR) analysis of newspaper.

The major absorption bands in the FTIR highlights the lignocellulosic components in the paper composing of aromatic alkynes and oxygen functional groups. The presence of broad band absorbent peak around 3693 – 3338 cm-1 is associated with the –OH stretching of the hydroxyl group. The band at 2899cm^{-1} corresponds to C-H stretching of non-aromatic compounds which is visible in the figure. A broad peak absorbent band was present in the range of 2348.2 – 2117.1 cm^{-1} which is responsible for O=C=O strong stretching. The peak band at 2094cm^{-1} is attributed to C=C=C medium stretching. The absorbent peak range 1595 – 1423cm^{-1} corresponds to asymmetrical stretching of N-O. 1982.2 – 16651.2 cm^{-1} absorption band in the sample is responsible for a weak C-H bonding indicating the presence of an over tune aromatic compound. Another peak was observed in the range of 1267 – 1028cm^{-1} which is responsible for the stretching of C-O. Das (2017) made similar findings with respect to broad band absorbent peaks in newspaper samples.

4.2 Tensile and Flexural strength of matrix and composite

Figure 3 shows the variation of the tensile strength (TS) of the developed Waste Newspaper Particulate Reinforced Composite (WNPRC). The tensile strength of the sample was observed to be increase with the addition of the waste newspaper particulate from 30.97 to 32.5MPa up to 20wt% filler loading. However, further addition of the particulate beyond 20wt% resulted in decreased TS. The increase in the TS value maybe due to the adhesion between filler and the polyester resin as a result of the alkaline + silane surface treatment of the filler. The decrease in TS beyond 20wt% filler loading may be due to poor or uneven dispersion of the filler within the polyester matrix. Another reason may be due to the increased formation of the micro space (voids) in the composite at higher filler loading. These research findings are similar to previous findings by Adhikaria & Gowda, (2017); Prabu *et. al.*, (2017) and Tabatabai, *et. al.*, (2017). Comparing the neat polyester sample with its composite samples, it indicates that the addition of filler increases the tensile strength of polyester with filler loading up to 20wt%.

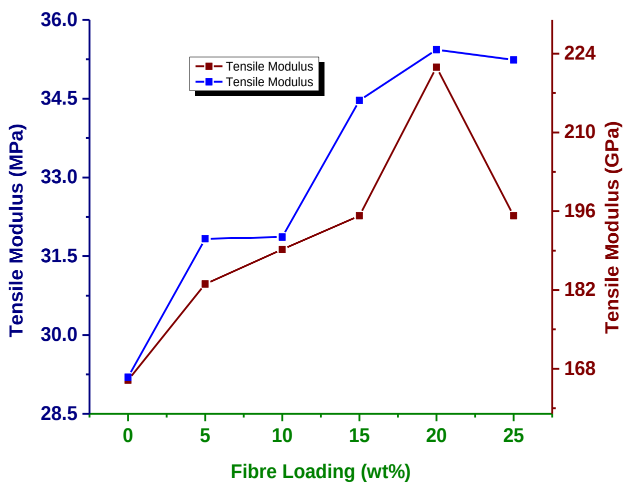


Figure 3: Variation of Tensile strength and Tensile Modulus with percentage of fibre loading.

The highest Tensile Modulus (TM) of the composite material was found to be 224.7 at 20wt% filler loading. It is evident that the addition of WNP improved the TM of the composite by 34.95%. The improvement in the TM is must noticeable in 15wt% and 20wt% samples (where the maximum TM is exhibited by the material). Samples with 15wt% and 20wt% WNP loading showed an increase in TM relative to the control sample by about 18.6% and 30.8% respectively. The increase in TM is likely due to detention in deformation of the polyester resin which brings about a reduction in tensile strain (Islam, *et al.*, 2017). The tensile properties (TS and TM) are expected to be on the increase with increase in the percentage of fibre loading due to good interfacial bonding between the WNP and the polymer matrix. The increase is expected to a certain limit at which it will be decreasing as observed in samples with the 25wt% fibre loading. This decrease is may be due to poor wetting and formation of micro pores which is associated with composite at higher percentages of reinforcement.

4.2.1 Flexural Strength

The Figure 4 shows the variation of the flexural strength (FS) and flexural modulus (FM) of the composite of varied filler loading. It can be observed that the FS of the composite sample decreased from 63.71 to 46.21MPa as the filler loading increased up to 25wt%. On the other hand, the FM of the composite was also observed to decrease from 32.09MPa at 5wt% to 25.37MPa as the composition of filler loading is increased up to 25wt%. Sigley, *et al.*, (1991) reported that polyester resins are usually brittle under tensile and flexural loading, hence the decrease in the FS of the developed composite relative to that of the polyester resin maybe due increase in the brittleness and reduction in the ductility property in the composite leading to a decrease in the FS value. This also validate the low deflection observed in the composite material.

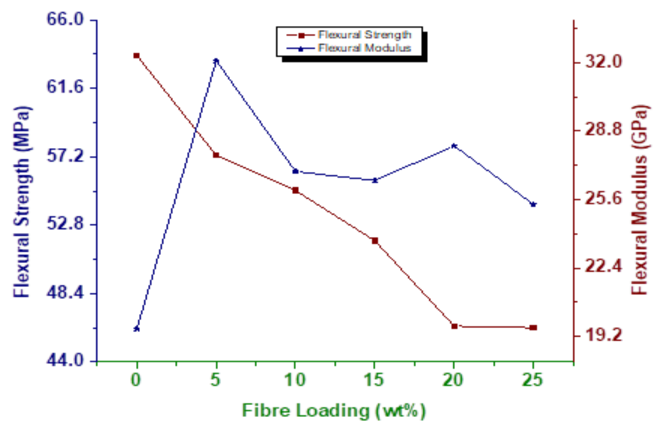


Figure 4: Variation of Flexural Strength and Modulus of developed composite with percentage of fibre loading.

At higher percentages of the WNP, the decrease may also be due to formation of voids, poor fibre/matrix interactions as higher filler percentages and uneven dispersion of particulates in the matrix. The flexural behavior shown by the composite material is similar to the findings of García, *et al.*, (2018) and Choudhury, *et al.*, (2017). For polymer matrix composite, with a decrease in the either the tensile or flexural/bending strength, the tensile and flexural modulus is expected to increase which will be as a result of the restrain deformation caused by the fibres (Islam, *et al.*, 2017).

4.3 Hardness Test Result

The hardness test result of the fabricated composite is presented in the Table 1 above, clearly shows the increase in the hardness value of the composite material as the percentage weight of the particulate reinforcement increases. The hardness value obtained at 5wt%, 10wt% and 15wt% were 31.6, 38.7 and 44.6 respectively. Further addition of the particulate fibre at 20wt% and 25wt% resulted in a decrease in the hardness value to 37.08 and 37.7 respectively. The maximum value was obtained at 15wt% while the minimum was at 20wt%. With the least hardness value obtained, an improvement in the value obtained for the hardness value of the control sample (pure unsaturated polyester) with about 25%. At lower fibre loading, there is even distribution of the fibre in the matrix which in turn increases the hardness value of the developed composite. At higher percentage of fibre loading of 20 and 25wt%, the hardness values was observed to decrease. The reduction is as a result of the uneven distribution of the fibre in the matrix resulting to poor wetting between the fibre and the polyester matrix. The poor distribution of the fibre in the matrix also resulted in the formation of voids within the material and the interface of the material and the casting mold. SEM micrographs of the 20wt% and 25wt% can justify the presence of air voids in the samples. Similar observations of poor fibre distribution in matrix was reported by Vaghasia & Rachchh (2018) made similar observations.

Table 1: Comparison of Hardness values of neat polyester with composite developed at varied filler loading.

S/N	Fibre Loading (wt %)	Hardness Value (HRF)
1	Neat Polyester	29.60
2	5	31.60
3	10	38.70
4	15	44.60
5	20	37.03
6	25	37.70

4.4 Impact Test Result

Impact test was conducted to determine the amount of energy that would be absorbed by the material before failure when subjected to impact loading. Figure 5 shows the variation of impact energy of matrix with that of composite at varying percentage loading of waste newspaper particulate. The result showed an increase in the impact energy of the composite as the percentage of particulate reinforcement filler increases from 5wt% up to 15wt%. However, for further increase in the particulate filler composition at 20wt% and 25wt%, the impact energy decreased to 3.23 KJ/m^2 and 3.07 KJ/m^2 respectively. Highest impact energy was observed to be 3.79 KJ/m^2 at 15wt% filler loading. The decrease in the impact energy of the composite material maybe as a result of increased voids formation associated with higher percentages of filler loading in composite compounding leading to a decrease in the impact energy. Another reason may be as a result of the poor compaction of the matrix and reinforcement at higher percentages. Similar result findings are obtained by (Farzi, *et al.*, 2019, Pradhan, *et al.*, 2019, Islam, *et al.*, 2017 and Munawara, *et al.*, 2017).

4.5 Scanning Electron Microscopy (SEM)

Figure 6 and 7 shows the SEM micrographs of the composite material at different weight percentage composition of fibre. In figure 5 (A and B) revealed even dispersion of the particulate in the matrix as well as good fibre/matrix bonding which made the material exhibit better properties at 10wt% and 15wt% composition.

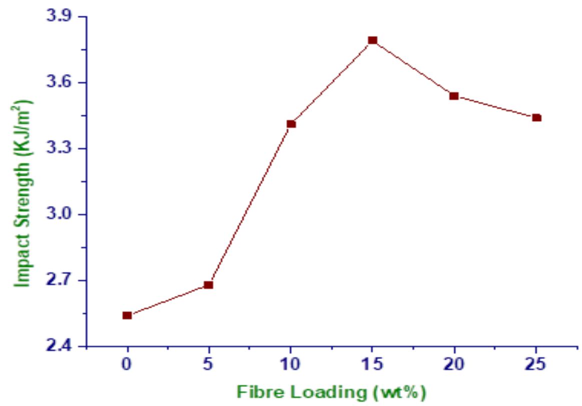
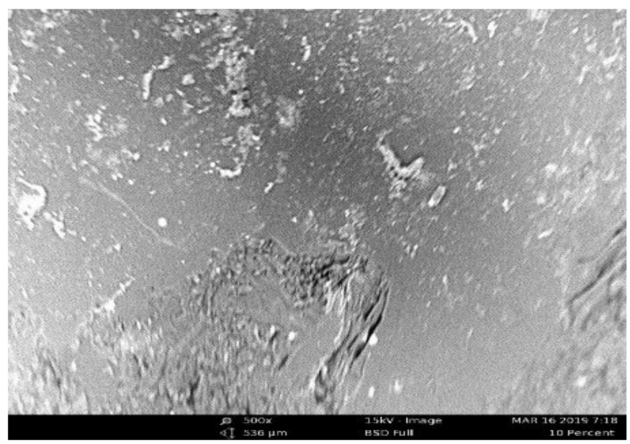


Figure 5: Variation of Impact strength of developed composite with fibre loading composition.

Good mixing and distribution of particulate in polymer matrix at higher composition of particulate reinforcement is always associated with some difficulties which always leads to improper and poor wetting and thorough mixing of matrix and reinforcement as well as formation of air voids with the material during and after casting. This effect can clearly be seen in the micrographs in Figure 6 (C and D). The air voids formed gave rise to the decrease in the properties of the material.



(a)

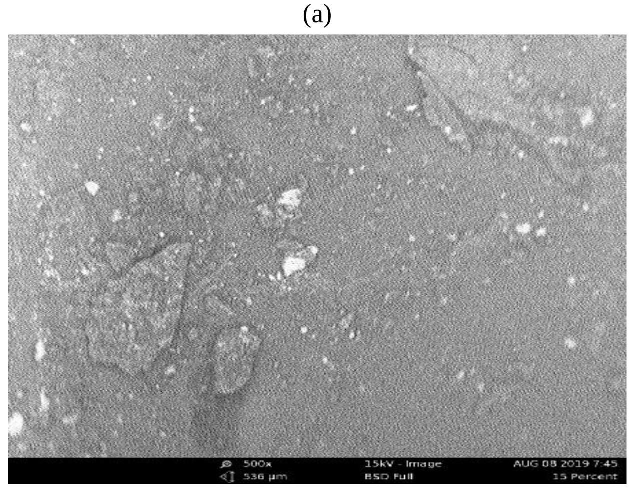
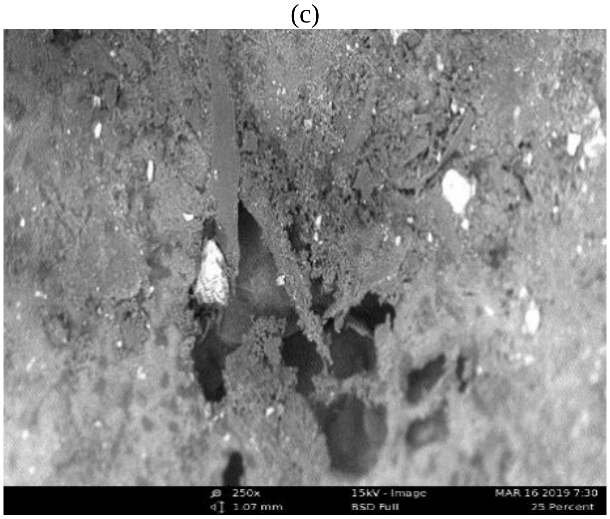


Figure 6: SEM Micrograph of 10wt% (a) and 15wt% (b) WNPRFC sample at 20kV operating voltage at 500X magnification.

(c)



(d)

Figure 7: SEM Micrograph of 20wt% (c) and 25wt% (d) WNPRFC sample at 20kv operating voltage at 500X magnification.

5. Conclusion

Experimentation and testing of waste newspaper particulate reinforced polyester composite at varied filler loading was carried out and the following conclusions can be drawn;

i. Best tensile properties were observed at 20wt% fibre loading with tensile strength and modulus of 35.1MPa and 224.7MPa respectively. Addition of waste newspaper particulate improved the tensile properties by 20.45% for TS, 34.95% for TM and 43.76% for flexural modulus.

ii. Optimum impact strength and hardness value were observed at 15wt% fibre loading. 3.79KJ/m^2 was observed as the maximum impact strength with about 49.21% increase to that of the neat polyester samples, while the maximum hardness value of 44.6HRF was recorded with about 50.68% increase to that of the neat polyester samples.

iii. SEM shows a good and even dispersion of the particulate filler and matrix at lower percentages of fibre loading. The result also showed the formation of voids beyond 15wt% of reinforcement leading to a reduction in the properties of the material.

iv. The tensile strength of the developed material is within the permissible range of 20 – 40 MPa for materials to be considered for automotive internal application such as dashboards, internal door panel and door map pocket application (Susilowati & Sumardiyanto, 2018 and Sapuan, *et al.*, 2011).

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