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Thermo-mechanical characterization of banana particulate reinforced PVC composite as piping material

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KEYWORDS

Particulate composite;
Mechanical characterization;
Spectroscopic analysis;
Piping material;
Cost per meter length;
Price per meter length

Abstract A banana particulate reinforced polyvinyl chloride (PVC) composite was developed with low cost materials having an overall light-weight and good mechanical properties. The specimen composite material was produced with the banana (stem) particulate as reinforcement using compression molding. The composition with optimum mechanical property of 42 MPa was estimated to have a long term stress value of 25 MPa corresponding to 40% loss in strength over a period of 32 years. This composition has a formulation of 8%, 72% and 20% of banana stem particulates (reinforcement), PVC (matrix) and *Kankara* clay (filler) respectively with corresponding water absorption of 0.79%, Young's Modulus of 1.3 GPa and a density of 1.24 g/cm^3. Thermogravimetric analyses showed that constituents of reinforcement/filler in the composite increased the thermal stability of the composite by 38.6% over that of pure PVC. The composite has better creep stability at elevated temperatures than PVC. Long term TTS (time–temperature-superposition) performance prediction at 50 °C showed the composite satisfied WLF assumption with reduced stiffness to 0.65 GPa over an estimated period in excess of 100 years of usage indicating better long term performance than PVC pipe material – the stiffness could be much higher when used below 50 °C. Comparison with conventional piping materials showed the composite offered a price savings per meter length of 84% and 42% when compared with carbon steel and PVC material.

1. Introduction

Conventional steel pipes used in petroleum industries are plagued by high cost of maintenance, corrosion and lower life cycles. The total annual cost of corrosion in the oil and gas industry is estimated at $1.372 billion, with $589 million representing pipeline and facility costs, downhole tubing expenses consuming $463 million and $320 million capital expenditures for corrosion control (Ruschau and Al-Anezi, 2003). The use

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Nomenclature

E	tensile modulus (GPa)	V	volume (cm^3)
F	maximum tensile force (N)	b	breath or width of a specimen (m)
l	original length for tensile specimen (cm)	t	thickness of a specimen (m)
e	change in length (mm)	r	internal radius of pipe (m)
W_{final}	weight of specimen after immersion (g)	R	external radius of pipe (mm)
$W_{initial}$	weight of specimen before immersion (g)	A	cross-sectional area (mm^3)
ρ	density (g/cm^3)		
m	mass (g)		

of composite pipe is expected to greatly reduce the economic losses (due corrosion and high cost of maintenance) and provides new investment opportunities. A composite (composite material) is a precise blending of two or more materials to create a new material that is stronger, lighter (less comparable weight) and easier to work with than alternative individual materials such as metal and plastic (ACM, 2011). Research in piping material is very significant as the networks of pipes in the US, Europe and Russia run to about 1,200,000 km (Berisa et al., 2005).

Composite primarily consists of matrix and reinforcement and in addition may contain a third component known as 'filler'. The filler is mixed with the matrix during fabrication and may not necessarily improve the mechanical properties but rather some aspects of desired considerations. Some examples of fillers are hollow glass microspheres for reduced weight and clay or mica particles for reduced cost (Gibson, 2011).

Several works have been carried out on development and characterization of composites. Nuher et al. (2014) developed a palm fiber reinforced acrylonitrile butadiene styrene (ABS) composite using injection molding machine (IMM) and found out that the density and water absorption increased with increasing percentage of fiber content while the tensile strength and flexural strength decreased with the exception of the fiber content at 5%. Sapaum et al., 2005 developed banana fiber reinforced epoxy composites and determined it mechanical properties. Tensile and flexural tests were performed and the maximum stress and Young's Modulus were determined as 25.18 MPa and 2.69 GPa respectively. Flexural test was observed at a maximum load of 36.3 N. Oseghale and Umeania (2011) evaluated the application of reinforced composite piping (RCT) technology vis-a-vis glass reinforced epoxy (GRE) for liquefied petroleum gas (LPG) as a substitute to the predominantly steel and plastic pipes.

Polymer matrix composites are viscoelastic in nature and thus time–temperature-superposition (TTS) is a useful technique in predicting its long term performance. Challa and Progelhof (1995) investigated the effect of temperature on the creep characteristics of polycarbonate and developed a relationship based on Arrhenius theory to develop creep master curves. Pooler (2001) applied TTS on wood-fiber reinforced HDPE and concluded that the material was thermorheologically simple and that only a horizontal shifting was adequate to correctly superimpose the creep data. Dynamic mechanical analysis (DMA) tests were used to determine the shift factors with only the storage modulus curves ignoring other viscoelastic parameters. Most literatures on composite pipes focused more on fiber layered reinforced composite pipes: Bakaiyan et al. (2009) developed multi-layered filament-wound composite pipes and analyzed its internal pressure and thermomechanical effect. Xia et al. (2001) developed filament-wound fiber-reinforced sandwich composite pipe and analyzed it based on internal pressure and thermo-mechanical loading. Ellyin et al. (1997) developed multi-directional filament-wound glass fiber/epoxy pipe and analyzed it based on biaxial loading.

Demand for engineering material with low density, high specific property, minimal corrosivity and low cost is on the increase for application in the aerospace and automobile industries (Thomas and Joseph, 2012; Kalia et al., 2009). In this study, Nigerian banana stem particulate was used as the reinforcement in the thermoplastic poly vinyl chloride (PVC) matrix. It was alkali treated to improve fiber matrix interaction of the produced composite. The composite is a three-constituent composition consisting PVC as matrix, banana stem particulate as reinforcement and *Kankara* kaolin clay as corresponding filler. *Kankara* kaolin clay is in abundance in *Kankara*, Katsina state of Northern Nigeria. The clay is available and accessible in most market in Northern Nigeria. Naturally clay types are corrosion resistant. Natural and synthetic constituents are used extensively in development of composite material. Polyvinyl chloride (PVC) is a widely used plastic, one of the most valuable products of the chemical industry and the second-largest thermoplastic commodity produced worldwide after polyethylene (Richardson and Edwards, 2009). PVC is naturally resistant to chemical attack (RP, 2015) and weighs lesser than most metals. It is less costly when compared to other polymers such ABS, LDPE and HDPE (Muzzy, 2015) and metals (i.e. aluminum powder, iron powder and magnesium). Natural fiber are in great abundance in Nigeria from variety of sources especially plant origins. Natural reinforcements have advantages over synthetic reinforcements as a result of the natural alignment of the carbon–carbon bonds and also its significant strength, stiffness (Jústiz-Smith et al., 2008) low density, low cost and biodegradability they offer.

The research work seeks to develop the composite as piping material that can have a potential application in the oil industry (distribution pipe networks) and household water piping application. The piping material constituents were selected to minimize the effect of corrosion and weight compared to conventional steel pipes used in the oil industry.

2. Experiment

2.1. Materials

Materials were selected based on availability, weight and corrosion resistance. Materials used are *Kankara* kaolin clay

(200 g), polyvinyl chloride powder (PVC, 500 g), banana stem (200 g), sodium hydroxide (NaOH), 1″ PVC pipe, mild steel mold and distilled water (5 L).

2.2. Preparation

The banana stem was cleaned and dried in the sun. The fibers were then manually removed by scrubbing on a rough surface and then cleansed with 1.5 M sodium hydroxide in accordance with Kalia et al. (2009) to enhance the fiber–matrix interface adhesion and later on dried in the sun (Essabir et al., 2013; Faruk et al., 2012). The fibers were then ground and sieved with a sieve size of 130 μm. The *Kankara* clay was also sieved with same sieve size.

Density of the banana particulate and *Kankara* kaolin clay (in powdery state) were determined using PVC (Anyalebechi, 2005) as the reference with known standard true density of 1.35 g/cm^3 in accordance with Dan-asabe et al. (2013). These were determined as 0.6 and 1.8 g/cm^3 for the banana particulate and kaolin clay respectively. The composition of banana particulate and PVC was varied. The particulate was varied from 0%, 8%, 16%, 24%, 32% and 40% respectively. PVC was varied accordingly from 80%, 72%, 64%, 56%, 48% and 40% respectively. The *Kankara* kaolin was kept constant at 20%. The composition of the constituents by weight is given in Table 1.

The mold was filled with the materials in such a way that after hot compression the composite will be reduced to half its initial volume to ensure excellent compaction (devoid of pores between the constituents) as shown in Fig. 1. Material used for the mold is carbon steel. The size of the groove for the mold is Φ40 × 120 mm. Each sample was put into the mold to fill it and the excess put off.

2.3. Compression molding process

This was carried out with Carver-3851 compression machine. Each sample was pressed at a temperature of 220 °C and a compression pressure of 20.7 MPa for 20 min. This temperature was used because preliminary trials with temperatures above it produced burnt product and temperatures below it produced less compacted product. The compression pressure (20.7 MPa) was the maximum pressure reached for the first test sample (reducing mold volume by half) and was adhered to for the remaining samples. Samples obtained were cooled and machined in preparation for characterization tests.

Table 1 Composition of constituents by weight.

Samples	Compositions (g)		
	Banana particulate	PVC	*Kankara* clay
Sample 1	0	44.0	11.0
Sample 2	4.4	39.6	11.0
Sample 3	8.8	35.2	11.0
Sample 4	13.2	30.8	11.0
Sample 5	17.6	26.4	11.0
Sample 6	22.0	22.0	11.0

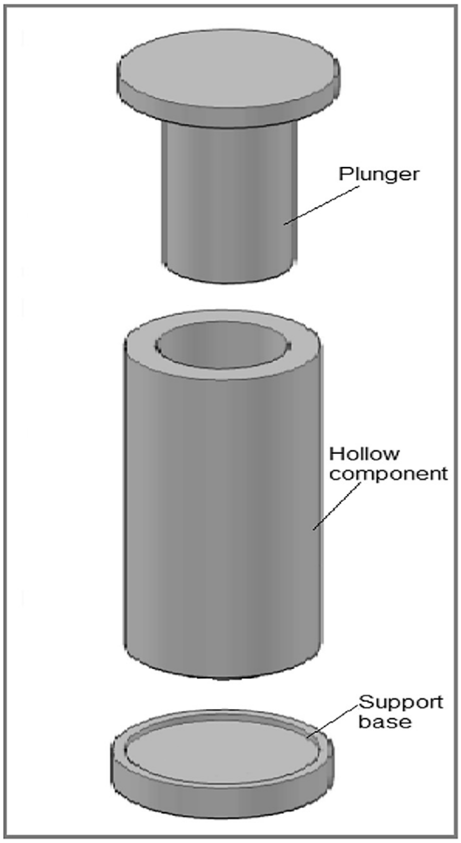

Figure 1 Composite mold.

3. Characterization

3.1. Physical and mechanical tests

3.1.1. Density and water absorption

The density of the composites was determined by measuring its respective mass and volume. Sample specimens of dimensions 20 × 20 × 5 mm were produced for the test. The mass was determined with the aid of a computerized weight balance machine to an accuracy of four decimal places. The volume of each sample was found using Archimedes's principle.

Water absorption test was carried out according to ASTM D570 (Klyosov, 2007) with oven-dried test specimen of dimension 60 × 25 × 5 mm immersed in water at ambient temperature for 24 h until equilibrium. The specimen was removed and patted dry with a cloth (lint free) and then weighed using a digital weighing balance. The dry weight before ($W_{initial}$) immersion and the weight after (W_{final}) immersion were noted. The water absorption was determined as follows:

$$W = \frac{W_{final} - W_{initial}}{W_{final}} (\%) \quad (1)$$

where $W_{initial}$ = initial weight before immersion and W_{final} = final weight after immersion.

3.1.2. Tensile strength and elastic modulus

Elastic modulus was determined using an Electronic Tensometer ER-3 according to ASTM D3039 (2014) standard. Sample specimen dimensions of 60 × 8 × 5 mm with dumb bell shape outside the gauge length were produced for the test. The dumb bell part was clamped to jaws of the machine and the extension was produced within the gauge span of the specimen. The elastic modulus was calculated by determining the slope of force-extension curve along the elastic region and then substituting in the following equation:

$$E = \frac{Stress}{Strain} = \frac{F}{e} \times \frac{l}{A} = Slope \times \frac{l}{A}(\mathrm{GN\,m^{-2}}) \qquad (2)$$

where E = Young's Modulus F = force, e = extension, l = original length and A = cross-sectional area.

The UTS was extracted from the plot of the force-extension diagram from the electronic tensometer as obtained.

3.2. Thermal tests

3.2.1. TGA/DTA

Perkin Elmer thermal analyzer was used to conduct thermogravimetric analysis on the sample composite. At the start of the experiment, the purge gas (nitrogen) was continuously passed into the furnace at a flow rate of 20 ml/min to condition the furnace. Sample with 8% particulate reinforcement (maximum tensile strength) was used for the test. The sample quantity of approximately 1 g was placed evenly distributed in an open pan of 6.4 mm diameter by 3.2 mm depth. The temperature was controlled from ambient to 830 °C at a heating rate of 10 °C/min and cooling at 20 °C/min (ASTM E1131, 2008; Seong et al., 2000). The test was carried out in FUT Minna Step-B new research center.

3.2.2. DMA, TTS and creep

DMA (dynamic mechanical analysis), TTS (time–temperature-superposition) and creep test were simultaneously carried out using DMA 242E machine in strength of materials laboratory of mechanical engineering, A.B.U. Zaria (ASTM D7028, 2015). The test parameters were first configured via the Proteus software using personal computer. Instruments set up that included the sample holder (3-point-bending), furnace temperature (range of 30–180 °C), furnace thermocouple and measurement mode (dynamic load at ±4 N, frequency range of 1–10 Hz and heating rate of 5 K/min.) were configured. For the creep test, the static load was set at 3 N. Sample specimens of dimension of 70 × 12 × 5 mm were produced for each test. The sample was loaded on to the machine using a three-point-bending sample holder and subsequently locked into the furnace.

4. Results and discussion

4.1. Physical and mechanical

4.1.1. Density

Graphical depiction of the density with increasing weight fraction of the particulate (reinforcement) indicated decrease in density of the composite (Fig. 2). The figure also shows the water absorption of the composite with increasing weight fraction of the particulates. The percentage water absorption of the composite increases as the weight fraction of the particulate is increased.

4.1.2. Tensile strength and elastic modulus

Fig. 3 depicts the modulus of elasticity of the composite with increasing weight fraction of the particulates. The trend of the modulus of elasticity (stiffness) of the composites increases from 1 GPa to 2.4 GPa. The figure also shows the ultimate tensile strength (UTS) of the composite with increasing weight fraction of the particulates. However the tensile strength increases and then decreases steeply. This could be due to weakening of the interfacial attraction of the constituent composition as the fraction of the PVC is reduced with increasing weight fraction of reinforcement. It is interesting to note that maximum is achieved at 8% weight fraction of the reinforcement.

It can be deduced that the optimum mechanical property was found at 0.79% corresponding to a density of 1.24 g/cm^3, UTS of 42 MPa and flexural strength of 92 MPa with appreciable water absorption of 2.7% and hardness value of 29.5Hv.

5. Thermal analysis

5.1. TGA/DTA

The result of thermal test (DTA and TGA) for composite of banana is shown in Fig. 4. The blue curve represents the DTA while the darker curve represents the TGA of the composite. The TGA measures the change in weight of the sample in relation to change in the controlled temperature. The curves showed the thermal scan between 29 °C and 830 °C. The onset temperature of decomposition (TGA) of the composite started at approximately 370 °C and continuously up to 530 °C with a corresponding mass depletion of 47%. The second stage of decomposition is 530–670 °C with a mass depletion of 23%. The total mass depletion from the thermal treatment is approximately 70%. The mass depletion is as a result of full decomposition of PVC and evaporation of some oxides of the kaolin clay and natural particulate substance (doum palm). Decomposition of PVC is a two-step process involving dehydrochlorination by releasing HCl and the formation of conjugated polyene sequences. The second step is the decomposition

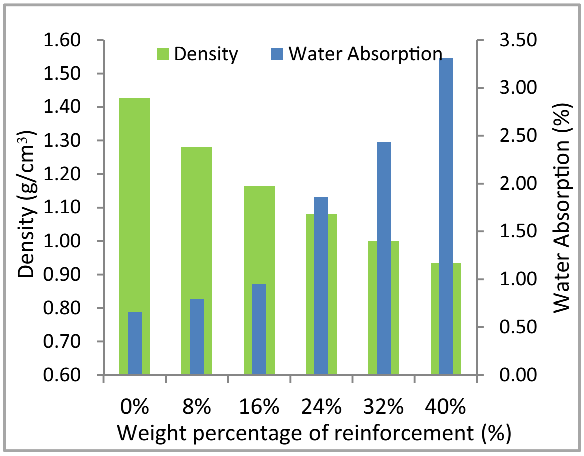

Figure 2 Effect of density and water absorption on weight percentage of reinforcement.

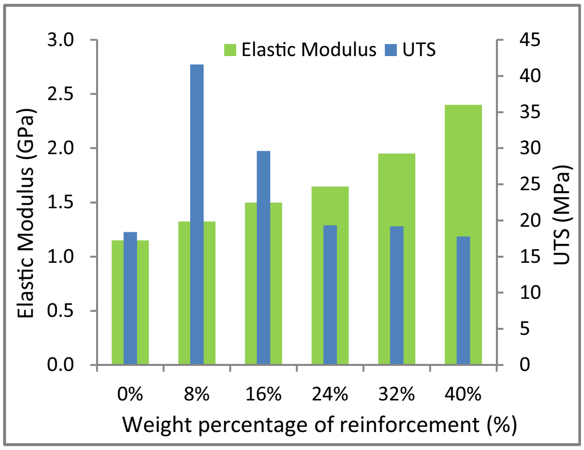

Figure 3 Effect of elastic modulus and UTS on weight percentage of reinforcement.

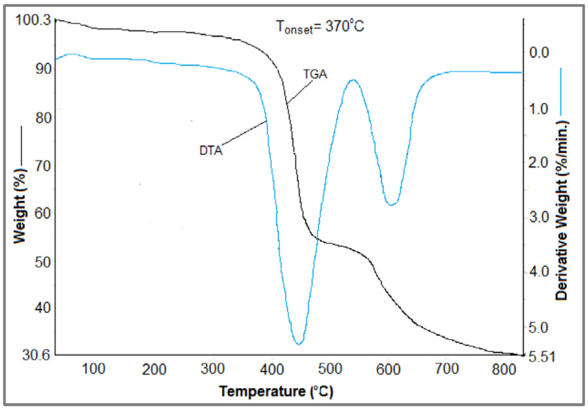

Figure 4 TGA/DTA curve of composite of banana particulates.

of polyene back bones and formation of residual chars (Xue et al., 2014). The DTA curve showed percentage mass decomposition rate for the two respective stages of 370–550 °C and 550–670 °C mass depletion. This was attributed to first and second stage decomposition of PVC and oxidation of some impurities of the banana and kaolin clay. Similarly, Fig. 5 depicts TGA/DTA curve of pure PVC with its mass decomposition stages of 267–390 °C and 390–510 °C respectively (Nagasaki et al., 2013). The curve showed a total mass depletion of 95% leaving only remains of the residual chars (5%). Comparison of figures showed that the composite has increase thermal stability over that of PVC by 103 °C. The TGA/DTA curves simultaneously showed that the composite is thermally stable up to a temperature of 370 °C.

5.2. DMA

The dynamic mechanical analysis (DMA) depicts the stiffness stability of the composite with increasing temperature, its glass transition temperature and its visco-elastic nature when stimulated by dynamic loading. The DMA curve of composite is depicted in Fig. 6. The test was carried out under a load stress of 150 KN/m^2 slightly above atmospheric pressure. The curve shows the composite is stable under dynamic loading (having zero strain) with increasing temperature at frequencies of 1, 5 and 10 Hz up to 70 °C before the onset glass transition temperature of 74.4 °C. The onset glass transition temperature of PVC is 80 °C and its point of inflection (mid-point) usually taken as the glass transition temperature is 85 °C (Mettler, 2016). The curve also showed about 22% loss of stiffness from 1.2 GPa to 0.9 GPa at 70 °C. This indicates the suitability of the use of the material up to 70 °C. The tan *d* (tan delta) value is the ratio of the viscous to elastic modulus and thus gives a measure of the visco-elasticity of the material. The visco-elasticity of composite of the banana particulate is eminent at tan delta value of 0.1 from 70 °C up to a maximum of 1 at 97 °C

Fig. 7 shows the curve for PVC 1″ pipe is stable under dynamic loading (having zero strain) with increasing temperature at frequencies of 1, 5 and 10 Hz up to 60 °C before its onset glass transition temperature of 65.8 °C. The curve also showed about 25% loss of stiffness from 2.25 GPa to 1.7 GPa at 60 °C. This indicates the suitability of the use of the material up to 60 °C. The visco-elastic nature of composite of the PVC is eminent at tan delta value of 0.1 from 60 °C up to a maximum of 1 at 75 °C.

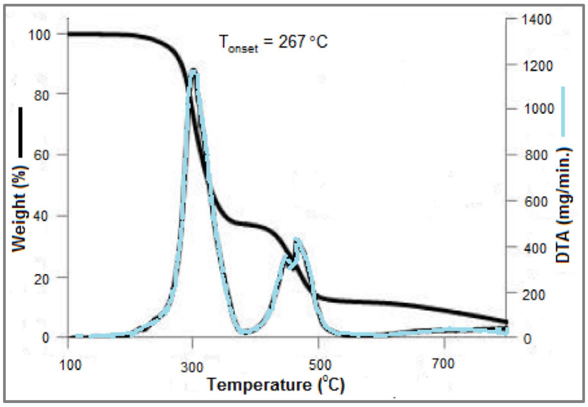

Figure 5 TGA/DTA curve of pure PVC (Nagasaki et al., 2013).

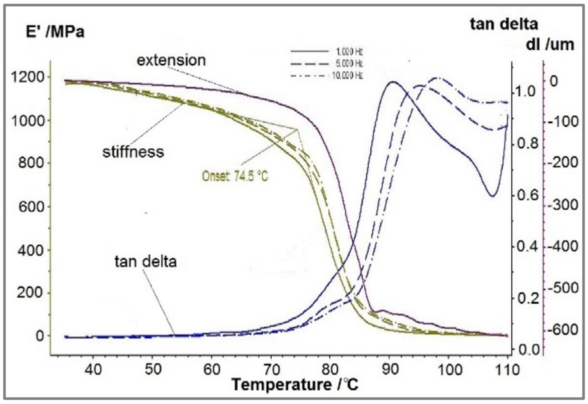

Figure 6 DMA test curve of composite of banana particulate.

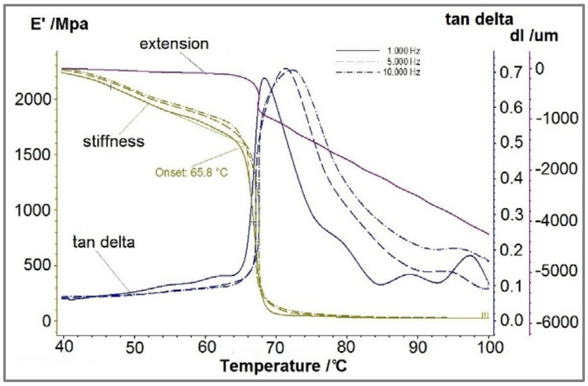

Figure 7 DMA test curve of PVC 1″ pipe.

5.3. TTS

Time temperature superposition (TTS) principle was used to predict the long term performance behavior of the composites using the DMA machine. Williams–Landel–Ferry (WLF) model was used as the TTS equation (at frequencies of 1, 5 and 10 Hz) where a master curve was generated depicting performance at extrapolated frequencies. Fig. 8 depicts the master curve for composite of banana at 50 °C. The test was carried out under a load stress of 150 KN/m^2. The curve shows the stiffness of the composite reduced to 0.72 GPa (40% loss in stiffness) after about 32 years (10^{-9} Hz). The stiffness is further reduced to 0.65 GPa (45% loss in stiffness) after about 126 years (2.5×10^{-10} Hz). However the stiffness may be much higher when used below 50 °C. Similarly, Fig. 9 depicts the master curve for 1″ PVC pipe at 50 °C with the stiffness reduced to 0.44 GPa (80% loss in stiffness) after 32 years (10^{-9} Hz) of usage. The stiffness is further reduced to 0.3 GPa (87% loss in stiffness) after about 126 years (2.5×10^{-10} Hz). Comparison of the results showed that the composite has better long term performance than the PVC 1″ pipe. The composite is rheologically simple as it satisfied the WLF condition of a cole–cole plot i.e. the experimental points must lie close to a single curve (a neat single curve without outliers) as shown in Fig. 10 (Butaud et al., 2015; Tajvidi et al., 2005).

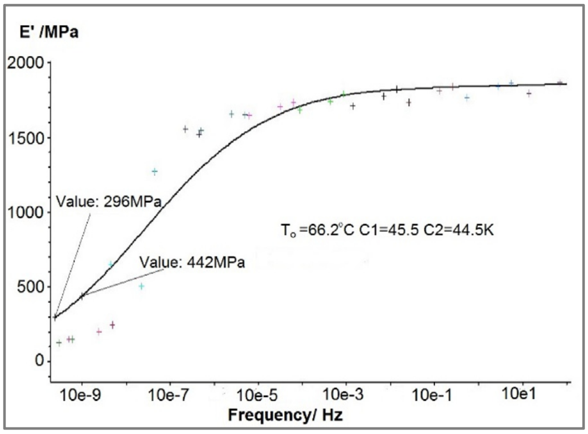

Figure 9 Master curve of 1″ PVC pipe at 50 °C.

5.4. Creep

Due to the visco-elastic nature of the composite materials, analysis of creep behavior is vital in understanding equilibrium strain rate. The result of the creep test for the composite at 70 °C is shown in Fig. 11. The creep test was conducted for 90 min at a load stress of 150 KN/m^2. The initial vertical large strain is due to the applied constant load after which the strain decreases with time up to about 50 min where the strain rate is very small known as the equilibrium strain rate. This stage is the secondary creep region and must be considered in load bearing capability of visco-elastic materials. The percentage strain during this period and temperature is 1%.

Similarly, Fig. 12 depicts the creep curve for PVC 1″ pipe at 70 °C for 90 min. The strain rate is fairly constant (not steadily decreasing) throughout the period and did not attain equilibrium. This showed that the PVC 1″ pipe material is not a good load bearing material (can fail with prolong usage) as compared to the composite as it did not attain equilibrium state within the same period and temperature. The PVC 1″ pipe material has a corresponding percentage strain during this period of 3.38%.

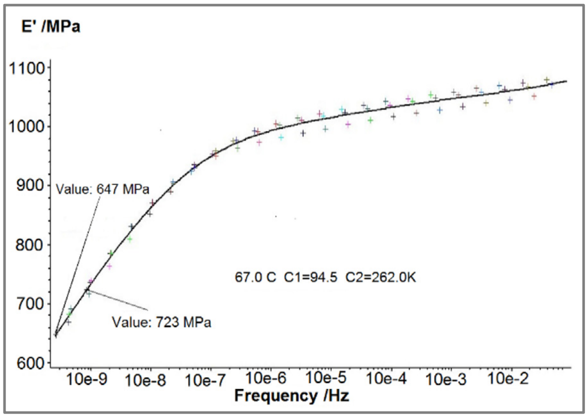

Figure 8 Master curve of composite of banana particulate at 50 °C.

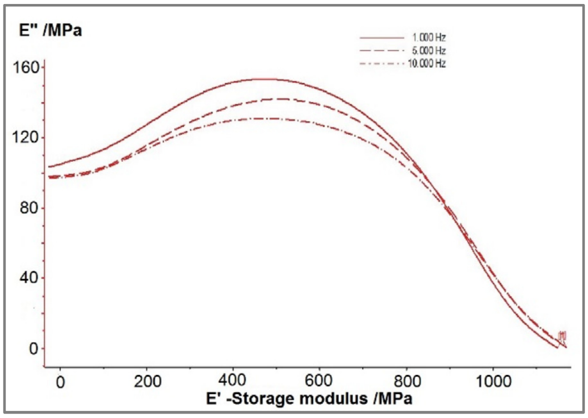

Figure 10 Cole–cole of composite of banana particulate at glass transition temperature.

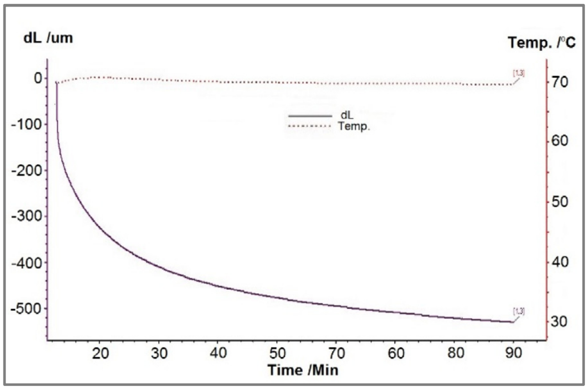

Figure 11 Creep curve of composite of banana particulate.

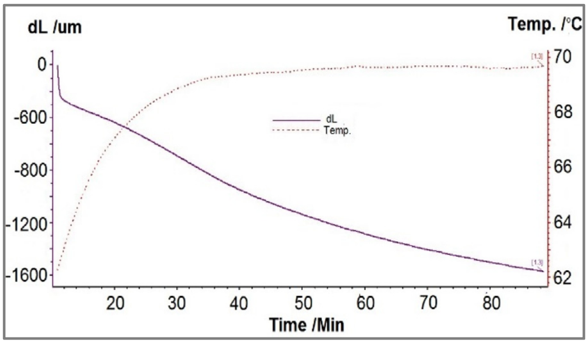

Figure 12 Creep curve of PVC 1″ pipe.

5.5. Comparative price and weight analysis with piping materials

Price and weight per meter length of the developed composite was compared with conventional piping materials of PVC and carbon steel as depicted in Fig. 13. Densities of carbon steel (Corrosionist, 2015) and PVC are given as 7.8 and 1.5 g/cm^3 respectively. The price of hemp and flax fibers (Karus et al., 2000) per kg are traded at DM0.55–0.65 ($0.31–0.37). Using analogical cost estimate for similarity with banana stem fibers, its initial price was estimated with respect to this price range per kg. Therefore, the lower price range was chosen and expenses as a result of fiber preparation were added resulting to a total of $0.8 per kg as shown in Table 2. Production cost was assumed $0.5 per kg to include profit and other expenses such as labor, power etc.

Cost of PVC pipe per meter length was $0.84/m for 2.5 mm, 1″ pipe and thus converted to $2.6/kg (Richardson and Edwards, 2009; Huaxin, 2016). Cost of carbon steel (Meps, 2016) was determined per kilogram weight at international market as $1.7/kg. Carbon steel of specification grade-A (ASTM A53) used extensively in oil industry for conveyance of gas, water and crude oil has tensile strength of 331 MPa and corresponding yield strength of 207 MPa (IG, 2016). However, the yield strength for steel material is used for pressure integrity analysis in accordance with ASME B31.1 (2001).

Weight per meter length was calculated as mass of the piping material per unit length of the pipe as (Eq. (7)):

$$m = \frac{\rho \times V}{l} \tag{3}$$

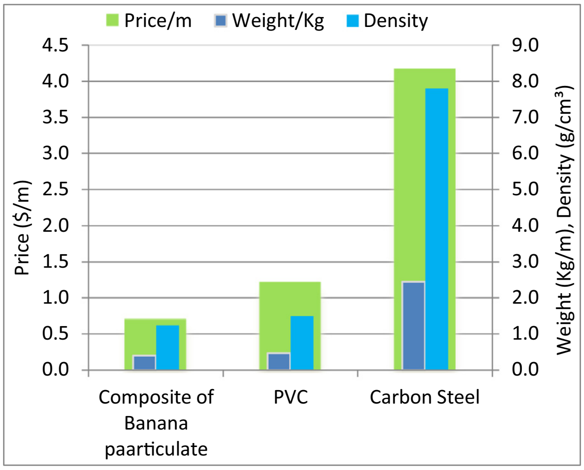

Figure 13 Price, weight per meter length and density of piping materials.

$$\text{but } V = \pi(R^2 - r^2)l = \pi l(R - r)(R + r) \tag{4}$$

$$\text{and pipe thickness, } = (R - r) \tag{5}$$

implying;

$$V = \pi l t(2r + t) \tag{6}$$

Therefore;

$$m = \rho\pi(t^2 + 2rt) \tag{7}$$

where R = outer radius, r = inner radius, t = thickness of pipe, V = volume of pipe material and l = length of pipe Comparison of weight per meter length at piping thickness of 3.5 mm was made for the three piping materials also as shown in Fig. 13. Carbon steel produced the highest cost and the largest weight per meter length thus implying higher mobility and installation cost. Material of composite of banana particulates gives the least weight per meter and at a cheaper price than PVC material. Material weight savings per meter length of 84% and 17% were achieved for the composite as compared with carbon steel and PVC material. Material price savings per meter length of 83% and 42% were achieved for the composite as compared with carbon steel and PVC material. The sample composite pipe was produced with the following parameters- 25 mm diameter, 4 mm thickness, 25 mm length and weight of approximately 15 g (see Plate 1).

6. Conclusion

The composite was developed with low cost materials having an overall light-weight and good mechanical property. The optimum mechanical property was determined at 8%, 72% and 20% formulation of banana stem particulates (reinforcement), PVC (matrix) and *Kankara* clay (filler) respectively, providing a corresponding density of 1.24 g/cm^3, Young's Modulus of 1.3GPa, negligible water absorption of 0.79% and tensile strength of 42 MPa.

Thermal analysis (TGA and DTA curves) simultaneously showed that the composite is thermally stable up to a temperature of 370 °C with increased thermal stability of 103 °C over

Table 2 Materials cost estimates of the composite and conventional pipe materials.

S/N	Materials		Percentage composition	Constituents price/kg	Price/kg	Weight/m	Price/m
1	Composite of banana						
	(a)	Banana	8%	0.80	1.83	0.40	0.71
	(b)	PVC	72%	1.70			
	(c)	*Kankara* clay	20%	0.20			
	(c)	Production cost		0.50			
2	PVC (gray color) pipe				2.60	0.47	1.22
3	Carbon steel pipe				1.70	2.45	4.16

Plate 1 Banana stem (particulate) reinforced PVC composite pipe.

that of PVC. DMA curve showed that the composite has higher glass transition temperature and better mechanical (stiffness) stability at higher temperature under dynamic loading than PVC pipe. The composite shifts glass transition temperature of PVC by 12 °C. The creep curve showed the composites have better creep stability at elevated temperatures than conventional 1″ PVC pipe material under constant loading, thus implying their load bearing suitability for piping application. Using long term TTS performance prediction at 50 °C showed that the composites have better long term performance than the PVC pipe during a period of 126 years of usage. Moreover, composite has better long term performance than PVC within the same period.

The composite was compared with carbon steel and PVC conventional piping materials. Material price savings per meter length of 84% and 42% were achieved for the composite as compared with carbon steel and PVC material. Material weight savings per meter length of 84% and 17% were achieved for the composite as compared with carbon steel and PVC material. Thus the composite can provide alternative potential material for piping application.

7. Recommendation

The composite pipe material is recommended for application at best temperature of not greater than 50 °C. Further research work should be carried out with other natural fibers such sisal, kenaf and bamboo to enhance knowledge capability and to broaden the possibility of substitute material components.

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References

ACM, 2011. Advanced Composite Materials: <http://www.a-c-m.com/> (accessed 03.04.11).

ASME B31.1, 2001. Pressure Piping. American Society of Mechanical Engineers.

ASTM D3039, 2014. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. ASTM International, West Conshohocken, PA.

ASTM D7028, 2015. Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA). ASTM International, West Conshohocken, PA.

ASTM E1131, 2008. Standard Test Method for Compositional Analysis by Thermogravimetry. In: Annual Book of ASTM Standards, vol. 14.02. ASTM International, West Conshohocken, PA.

Bakaiyan, H., Hosseini, H., Ameri, E., 2009. Analysis of multi-layered filament-wound composite pipes under combined internal pressure and thermomechanical loading with thermal variations. Compos. Struct. 88, 532–541.

Berisa, M., Lesis, V., Didziokas, R., 2005. Comparison of pipe internal pressure calculation methods based. J. Mechanika 4 (54), 5–12.

Butaud, P., Placet, V., Klesa, J., Ouisse, M., Foltête, E., Gabrion, X., 2015. Investigations on the frequency and temperature effects on mechanical properties of a shape memory polymer (Veriflex). Mech. Mater. 87, 50–60.

Challa, S.R., Progelhof, R.C., 1995. A study of creep and creep rupture of polycarbonate. Polym. Eng. Sci. 6, 546–554.

Corrosionist, 2015. <http://www.corrosionist.com/what_is_the_densities_of_steel.htm> (accessed 05.05.15).

Dan-asabe, B., Yaro, S.A., Yawas, D.S., Aku, S.Y., 2013. Water displacement and bulk density-relation methods of finding density of powdered materials. Int. J. Innov. Res. Sci. Eng. Technol. 2 (9), 5561–5566.

Ellyin, F., Caroll, M., Chiu, A.S., 1997. The behaviour of a multidirectional filament-wound glass-fibre/epoxy tubular under biaxial loading. Compos. Sci. Technol. 28 (9), 781–790.

Essabir, H., Hilali, E., Elgharad, A., El Minor, H., Imad, A., Elamraoui, A., et al, 2013. Mechanical and thermal properties of bio-composites based on polypropylene reinforced with Nut–shells of Argan particles. Mater. Des. 49, 442–448.

Faruk, O., Bledzki, A.K., Fink, H., Sain, M., 2012. Bio composites reinforced with natural fibres. Prog. Polym. Sci. 37, 1552–1596.

Gibson, F.R., 2011. Principle of Composite Material Mechanics. CRC Press, Florida, US.

Huaxin, Tiger, 2016. < http://huaxintiger.en.alibaba.com/?spm = a2700.7765678.0.0.NlWVVo > (accessed 17.03.16).

IG, 2016. Industrial Group. Specification for steel pipes. < http://industrialgroupco.com/common_steel_pipes > (accessed 17.03.16).

Jústiz-Smith, N.G., Virgo, G.J., Buchanan, V.E., 2008. Potential of Jamaican banana, coconut coir and bagasse fibres as composite materials. Mater. Charact. 59, 1273–1278.

Karus, M., Kaup, M., Lohmeyer, D., 2000. Study on Market and Price of Natural Fibres. Nova Institute, Germany. http://www.nova-institut.de/pdf/nova-study-full.pdf, (accessed 02.11.16).

Kalia, S., Kaith, B.S., Kaur, I., 2009. Pretreatments of natural fibers and their application as reinforcing material in polymer composites-a review. Polym. Eng. Sci. 49 (7), 1253–1272.

Klyosov, A.A., 2007. Wood-Plastic Composite. John Wiley and Son Inc., New Jersey, US.

Meps, 2016. < http://www.meps.co.uk/indian%20steel%20price%20index.htm > (accessed 05.03.16).

Mettler, Toledo, 2016. Thermal Analysis of Thermoplastics. < http://www.us.mt.com/thermal_analysis_of_thermoplastic.pdf > (accessed 03.02.16.

Muzzy, J.D., 2015. Thermoplastics – Properties. Georgia Institute of Technology, Atlanta, GA, USA. < http://www-old.me.gatech.edu/jonathan.colton/me4210/thermoplastchap.pdf > (accessed 23.08.15).

Nagasaki, Y., Hashimoto, G., Grase, G., Kameda, T., Yoshioka, T., 2013. Modification of PVC with long alkyl chains by nucleophilic substitution. 7th international Symposium on Feedstock Recycling of Polymeric Materials, New Delhi, India.

Nuher, B., Bhuiyan, M.M.R., Kabir, H., Qadir, M.R., Gafur, M.A., Ahmed, F., 2014. Study of mechanical and physical properties of palm fibre reinforced ABS composite. Mater. Sci. Appl. J. 5, 39–45.

Oseghale, I.C., Umeania, N.H., 2011. Application of reinforced composite piping (RCP) technology to liquefied petroleum gas distribution. Medwell J. Appl. Sci. 6 (3), 197–204.

Pooler, D.J., 2001. Master's Thesis, Washington State University.

Richardson, R., Edwards, M., 2009. Vinylchloride and organotin stabilizers in water contacting new and aged PVC pipes. Water Research Foundation, 6666 West Quincy Avenue, Denver, US.

Ruschau, G.R., Al-Anezi, M.A., 2003. Oil and Gas Exploration and Production. Retrieved from < http:/corrosionda.com/prodmanu/oilgas/index.htm > .

RP, 2015. Rutland Plastics. < http://www.rutlandplastics.co.uk/advice/abs.html > (accessed 23.08.15).

Sapaum, S.M., Leenie, A., Harium, M., Beng, Y.K., 2005. Mechanical properties of woven banana fibre reinforced epoxy composites. Mater. Des. 27, 689–693.

Seong, X.L., Wu, J.M., Ko, S.W., 2000. Synthesis of quaternary ammonium derivative of chito-oligosaccharide as antimicrobial agent for cellulose fibres. J. Appl. Polym. Sci. 76 (14), 2009–2015.

Tajvidi, M., Falk, H.R., Hermason, C.J., 2005. Time-temperature principle applied to Kenaf-fibre/HDPE composite. J. Appl. Polym. Sci. 97, 1995–2004.

Thomas, S., Joseph, K., 2012. In: Polymer Composites, first ed., vol. 1. Wiley VCH Verlag GmbH & Co. KGaA.

Xia, M., Kemmochi, K., Takayanagi, H., 2001. Analysis of filament-wound fibre-reinforced sandwich pipe under combined internal pressure and thermomechanical loading. Compos. Struct. 51, 273–283.

Xue, X., Zhang, H., Zhang, S., 2014. Preparation of MgAl LDHs inercalated with amines and effect on thermal behavior for polyvinyl chloride. Adv. Mater. Phys. Chem. 4, 258–266.