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

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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 of composite

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Nomenclature

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

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 thermomechanical loading. Ellyin et al. (1997) developed multidirectional 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