American Journal of Mechanical and Materials Engineering
2022; 6(4): 44-50
http://www.sciencepublishinggroup.com/j/ajmme
doi: 10.11648/j.ajmme.20220604.11
ISSN: 2639-9628 (Print); ISSN: 2639-9652 (Online)

Design and Development of Plantain Fibre for Application in Production of Oil and Gas Facilities

Nnorom Obinichi*, Nwosu Herold, Tobinson Briggs

Mechanical Engineering, University of Port Harcourt, Port Harcourt, Nigeria

Email address:
Obinichi.nnorom@uniport.edu.ng (Nnorom Obinichi)
*Corresponding author

To cite this article:
Nnorom Obinichi, Nwosu Herold, Tobinson Briggs. Design and Development of Plantain Fibre for Application in Production of Oil and Gas Facilities. *American Journal of Mechanical and Materials Engineering*. Vol. 6, No. 4, 2022, pp. 44-50. doi: 10.11648/j.ajmme.20220604.11

Received: September 20, 2021; **Accepted**: October 11, 2021; **Published**: January 17, 2023

Abstract: This research established reasons why industries, especially in the oil and gas are looking at plantain fibre which is a natural fibre composite due to low price, weight reduction, easy to recycle and are green in nature and so on; when compared to petroleum-based fibres. The plantain will be cut, retted, extracted, dried, treated, and modified. The tensile, hardness properties of untreated and treated plantain fibres as well as their densities will be investigated. The fibres developed in the research exhibit good mechanical properties in terms of tensile strength, hardness and density. These treatments improved the hydrophobic property of the developed fibre, the density of the untreated and alkali treated fibre gave 0.021g/cm^3 and 0.040 g/cm^3. The test conducted for strength on the mercerization treated fibres dried at different oven temperature of 30°C, 50°C, 70°C using 50mm, 60mm and 70mm fibre length. Based on the experimental results, oven temperature of 70°C at 80mm fibre length gave the highest strength of 706Mpa for mercerization treated fibre. At 50°C oven drying temperature gave 689Mpa using 50mm fibre length. At temperature of 30°C gave 682Mpa using 80mm fibre length. The mercerization modified fibre on 10% NaOH concentration at temperature of 70°C gave the optimum highest strength of 706Mpa at 80mm fibre length. Based on the results, the 70°C oven bath temperature is therefore adopted and accepted as the benchmark for developing the fibre. The developed fibre composite can be reinforced for production of test samples and products of oil and gas component such as piping, pipeline systems and pressure vessels among others.

Keywords: Plantain Fibre, Tensile Strength, Mercerization

1. Introduction

Environmental awareness increase has influence engineering materials design greatly all over the globe. The use of natural materials addresses ecological issues currently in the area of recyclability and environmental safety. Recently, due to specific strength and increase in stiffness in manmade fibers like aramid, glass and carbon have been used in plastics matrix [1]. Synthetic fiber possesses superior strength; they have some drawbacks such as poor recyclability, high cost and non-biodegradability. Research conducted in past years was directed in development and natural fibers cost-effectiveness [2]. The natural fibers composites are significant because of its sustainability; they are cheap and are biodegradable also non-toxic compare to other manmade fibre (synthetic fibers). Furthermore, since natural fibres are naturally hydrophilic, that has reduced their compatibility with hydrophobic polymer matrices. The surface of the fibre and hydroxyl groups lead to ineffective fiber-polymer matrix bonding due to the presence of a waxy substance. Swelling within the polymer matrix was caused by high moisture absorption of the fibre which has leads to dimensional instability [3]. Due to the difference in chemical structure between the two constituents, it is very challenging to obtain a strong bond between NFs and polymer matrices. In most cases, the problem is ineffective stress transfer through the fiber-matrix interface [1]. Various physical and chemical treatments are applied in order to enhance the fiber-matrix adhesion and to improve the properties of NFs. Among them is mercerization treatment which involves the treating the fibre with sodium hydroxide (NaOH). Earlier studies of mercerization/alkali treatment have revealed that alkali concentration used, its effectiveness depends mainly on the type of fiber, the soaking temperature and its duration [4].

These fibers are extracted from plants and natural fibre has comparable mechanical properties to manmade fibers. Natural fibre with polymer matrix has been used to produce seat backs, door panels, headliners, dash board, package trays and many interior parts by car manufacturers. Many products have been manufactured from natural fibers which are derived from flax, sisal, and hemp plants [6]. Natural fibre has some shortcomings and attractive qualities which limit their application in many structural areas. Natural fibres possess high variability in properties [7]. The application of coupling agents and chemical treatment were effective to enhance bonding with the polymers.

Therefore, emphatically, natural fibres have become attractive to researchers, engineers and scientists as an alternative reinforcement for fibre reinforced polymer (FRP) composites. They are exploited as a replacement for the conventional inorganic fibres, such as glass, aramid and carbon. This has made composite application more attractive in the sub-sea application in the areas of down-hole tubing and others. The determination of composite mechanical strength, durability when exposed to liquid depend resin selection made. The offshore application that is most successful for natural fibre composites is in the area of pipe work for aqueous liquids. The design performance-based guidelines for of natural fibre reinforced epoxy (NFRE) pipes have drastically hastened the application in the offshore sector. The United Kingdom Offshore Operators Association (1994) initiated it and became a standard ISO draft (ISO, 2000). It is also, observed that the most major structural materials, epoxy, polyester and vinyl ester, can be prohibited from use in areas where toxicity and smoke will be a difficulty [10]. Modar, the modified acrylic resins can be applied in definite toxicity-sensitive areas, which is not broadly used offshore while the natural fibre reinforced epoxy is broadly used in pipe and tubular works. Table 1 and 2, list current application of natural fibre composites with their near future used.

Table 1. *Current applications of natural fiber composites for oil and gas, off-shore applications [10].*

S/No	Application
1	Composite Grids/ Gratings
2	Hand rails and Ladder Components
3	Aqueous Piping System
4	Water and fuel storage tanks, Vessels
5	Low pressure composite valves
6	Spoolable type thermosetting tubes
7	Sump Caissons and pull tubes
8	Cable support systems
9	Modular paneling for partition walls
10	High pressure accumulator bottles
11	Flexible and Floating Risers, Drill pipe
12	Sub - sea structural components
13	Boxes, housings and shelters
14	Fire water pump casing and sea water lift pump casing
15	Tendons
16	Offshore bride connecting between platforms
17	Blast and Fire protection

Table 2. *Future applications in oil and gas, offshore facilities.*

Rigid Risers	Coilable Turbing	Flexible Risers
Tendons	Primary Structures	Separators

According to [11] the application of natural fiber composite has gained more grounds than glass and carbon fiber. Although, glass and carbon are higher in strength compared to natural fiber but mostly preferred by the oil and gas industries due its reduced weight, recycling, and market enticements. This research focuses on development of plantain fibre which can be reinforced with plastic to produce oil and gas pipeline and piping system and pressure vessel etc.

1.1. Design of Oil and Gas System

Oil and gas facilities can be design and developed by using standard equations (1) to (7). The product system from oil and gas contain fluid which they will never absorb, there is need for permeability of the storage and pipeline material. The Crawford equation will be stated as permeability in relation to constant of permeation [12]

$$K = \frac{Q}{Atp} \tag{1}$$

where

Q = Fluid volume passing through the plastic material, d = plastic thickness, A = area exposed, t = time, P = difference in pressure across surfaces of plastic material. Using plastic multi - layers, keeping permeation constant which can be written as

$$\frac{1}{k} = \frac{1}{d}\sum_{i=N}^{i=N} \frac{d_i}{k_i} \tag{2}$$

By the relatively loose packing of the molecules means that gases and liquids can permeate through the plastics, the low density of plastics is an advantage in many situations. The yield strength of material, is another factor that is needed in the design of pipeline materials. Which is written using Barlow equation of pipeline material [14] as

$$\sigma_h = \frac{p^D code}{2t_{code}} \leq \emptyset_{code}\sigma_y \tag{3}$$

σh = hoop stress, σy = yield stress (YS), $D\ c\ o\ d\ e$ = pipe diameter, $\emptyset c\ o\ d\ e$ = factor of design, p = internal pressure. Similarly, stress analysis equations for pipeline material are written using design code. The wall thickness determination is the first to be considered and can be written as

$$T_m = \frac{pD_O}{2(SE+py)} + A \tag{4}$$

T_m = thickness of the wall in mm, p = pressure of design in Kpa, D_o = outside diameter of the pipe in mm, S E = allowable stress in Kpa, y = 0.4, A = 3mm (where y - the corrosion and A - erosion allowance in the pipeline). For pressure containment in most cases, pipeline standards have wall thickness requirements - standards of design in wall thickness is important based on limiting the internal pressure of the pipe hoop stress due to an allowable stress equivalent to the YS (σy) x $\emptyset$-$c\ o\ d\ e$. The maximum factors of design

for numerous codes are expressed in [14]. Based on international codes, the maximum allowable design factor varies from 0.72 to 0.80. The puncture resistance is necessary in the design of pipeline system which is written as

$$PR = [1.17\text{-}0.0029\ (D/t)] \times (L + W)\ (t \times \sigma_u) \quad (5)$$

t = thickness of the pipe wall, D = outside diameter of the pipe, W and L = width and length of digger tooth, σu = ultimate tensile test. Similarly, impact strength of the pipeline or toughness is necessary in the selection of pipeline material. Several known methods are used to stipulate a Charpy toughness to stop occurring fractures. For pipeline material, classical equation for toughness is written as

$$C_v = 2.836 \times 10^5 \sigma_h{}^2 (D)^{1/3} (t)^{1/3} \quad (6)$$

Cv = V-notch charpy energy in Joules, σh= hoop stress in N/mm^2, D = diameter of pipe in mm, t = thickness of pipe wall in mm

From equation (3) it can be seen that diameter of pipe, thickness of wall and factor of design are the most important parameter in design of pipeline system. The factor of design can be written as

$$\text{Factor of design} = \frac{\text{hoop stress}}{\text{yield stress}} \quad (7)$$

Furthermore, for design of piping, pipeline and pressure vessels system classical equations are obtainable. The equations comprise materials limiting stresses and thickness of wall for pipes and storage pressure vessel as written in the following equations. Moreover, the classical equations for thin walls, thick walls design as connected to pipe and pressure vessels system design are available in standard text books.

1.2. Pressure Vessels Design

In the development of composite materials, the yield strength, Poisson's ratio and elastic limit are required during selection and designing a pressure vessels system to contain external and internal pressurization effects. Many standard researches have stated models to study the containers thickness for pressure vessels to comprehend the internal pressures. The design of pressure vessel as thin or thick-walled cylinder where circumferential (hoop) stresses and longitudinal stresses are developed based on internal pressurization. A vessel or cylinder is said to be thin walled if:

$$\frac{t}{d} \leq 0.1 \quad (8)$$

Whereas a vessel is said to be thick walled if:

$$\frac{t}{d} \geq 0.1 \quad (9)$$

1.3. Design of Thin Wall Cylinders

Circumferential tensile (hoop) stress is written as

$$S_1 = \frac{t}{d} \quad (10)$$

The longitudinal tensile stress is written as

$$S_2 = \frac{t}{d} \quad (11)$$

Where S_1 = Circumferential stress, S_2 = longitudinal stress, P = internal pressure, d = internal diameter, t = thickness of the wall.

1.4. Design of Thick-walled Cylinders and Pressure Vessel System

When designing a thick-walled cylinder with closed ends subjected to internal pressure Pi, stresses are induced as shown in figure 1.

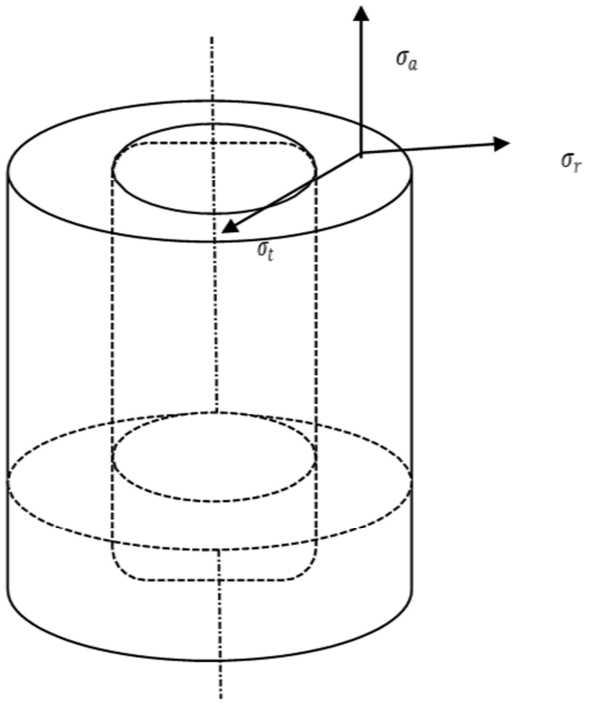

Figure 1. *Principal stresses of pressurized cylindrical and pipe vessel [13].*

To design a cylinder with thick wall subjected to internal pressure P_i, axial, radial and tangential stresses $\sigma_\alpha, \sigma_r, and\ \sigma_t$ are induced. The induced stresses are called principal stresses.

1.5. Lame's Equation

The principal stresses for internally and externally pressurized cylinders based on lame's classically equation of are written as

$$\sigma_r = \frac{P_i r_i^2 - P_o r_o^2}{r_o^2 - r_i^2} - \frac{(P_i - P_o) r_o^2 r_i^2}{r_o^2 - r_i^2} \frac{1}{r^2} \quad (12)$$

$$\sigma_t = \frac{P_i r_i^2 - P_o r_o^2}{r_o^2 - r_i^2} + \frac{(P_i - P_o)}{r_o^2 - r_i^2} \frac{r_o^2 r_i^2}{r^2} \quad (13)$$

where

r= radial distance of any point on cylinder, r_o = cylinder outside radius, r_i = cylinder inside radius.

The inside surfaces of the cylinder, stress analysis reveal

that both induced radial and tangential stresses are higher. Let's assume that no external pressurization (12) and (13) will reduce to

$$S_t = \frac{P_i r_i^2}{r_o^2 - r_i^2}\left(1 + \frac{r_o^2}{r^2}\right) \quad (14)$$

$$S_r = \frac{P_i r_i^2}{r_o^2 - r_i^2}\left(1 - \frac{r_o^2}{r^2}\right) \quad (15)$$

For thick-walled cylinder axial stress with closed ends subjected to an internal pressure is written as

$$S_a = \frac{P_i r_i^2}{r_o^2 - r_i^2} \quad (16)$$

At the inside surface of the cylinder maximum tangential stress (due to internal pressure) will be

$$S_t(max) = \frac{P_i(r_o^2 + r_i^2)}{r_o^2 - r_i^2} \quad (17)$$

The radial maximum stress is written as

$$S(max) - P_i \quad (18)$$

1.6. Brittle Material Design and Stresses

Principal stress is equal to tangential stress and for the biaxial system, it is maximum in cylinder design of brittle material in agreement with the maximum-stress theory (MST) of failure, this should not exceed, or

$$S_t = S_t\,(max)\,\frac{P_i(r_o^2 + r_i^2)}{r_o^2 - r_i^2} \quad (19)$$

But $t = r_0 - r_i$ the cylinder thickness is made of material with brittle behaviour.

$$t_i = r_i\left(\sqrt{\frac{S_t' + P_i}{S_t' + P_i}} - 1\right) \quad (20)$$

Equation (20) can be used to analyze open and closed cylinders system.

1.7. Determination of Thickness of Ductile Material

Failure is assumed to occur for ductile materials at the beginning of yielding maximum shear stress theory (MSST), at a particular point the maximum shear stress at any point in a stressed body is equal to one-half the algebraic difference of the maximum and minimum principal stresses. For a cylinder with thick-walled subjected to an internal pressure, the maximum shear stress occurs at a particular point on the inner surface (r-r_i). Therefore, the thickness can be written as

$$t = r_i\left(\sqrt{\frac{S'}{S_s' + P_i}} - 1\right) \quad (21)$$

$$S_s' = \frac{S_t'}{2} \quad (22)$$

1.8. Theory of Maximum–Strain

At the inner surface of a thick-walled cylinder, the maximum strain occurs and the thickness is expressed as

$$t = r_i\left(\sqrt{\frac{S_t' + (1-v)P_i}{S_t' - (1+v)P_i}} - 1\right) \quad (23)$$

Equation (23) is the Birnie's equation for cylinder with open end.

Recall that

$$t = r_i\left(\sqrt{\frac{S_t' + (1-2v)P_i}{S_t' - (1+v)P_i}} - 1\right) \quad (24)$$

Equation (24) is the Clavarino's equation for cylinders with closed-end

Finally, for ductile material equation

S_t' = allowable tensile, stress

= elastic limit / factor of safety or yield strength / factor of safety

The stresses acting in pressure vessels are markedly affected by the openings for manholes, hard-holes, nozzle attachments, and other connections and should be considered carefully especially when installing high pressure- high temperature materials.

2. Materials and Methods

2.1. Materials

The plantain fibres were obtained from a plantain plantation in Omuigwe Aluu in Ikwerre Local Government Area of River State. In this study, the following materials were used; they comprise of distilled water, weighing scale, oven, thermometer, pH meter and graduated cylinder, glass beaker, plastic cup.

2.2. Methods

2.2.1. Water Retting and Fibre Extraction

The fibre was extracted and retted by retting method a process of soaking the plantain in water. The remnants of the plantain were soaked in water using about 2% detergent for three days until the fibres are distinct from pectin, hemicelluloses, oily substances, and other impurities. After that, the fibres were thoroughly washed and allowed to dry in the sun for two days.

Figure 2. *Omuigwe Aluu plantain plantation in Ikwerre Local Government Area of Rivers State.*

Figure 3. *Extraction of plantain fibers.*

Retting is a rotting process of the fibre in water. Plantain fibre was soaked in water for days until the fibres are free from impurities. The plantain was retted for some days in Engineering Materials Laboratory at University of Port Harcourt. The fibres retted were dried at varying oven temperatures for constant weight and subsequently, relevant physical and mechanical properties were determined before and after various modification treatments.

Chemical Treatment of the PFs

The fiber was modified using [5] mercerization treatment techniques.

(a) Mercerization (Alkalization) Treatment

After cleaning the fibres, it was soaked using 10% sodium hydroxide (NaOH) solution at a temperature of 30ºC for an hour. Later the fibres were removed from the NaOH solution and washed thoroughly using plentiful of distilled water to remove all the excess NaOH (or nonreacted alkali).

2.2.2. Plantain Fibre Characterization

Hardness and Tensile test were investigated to analyze the hardness and strength for mercerization (alkalization) modified fibre using 10% concentration of NaOH to determine the soaking time in minutes for 60(1hr), 120(2hr), 180(3hr) and 240(4hr) at varying fibre length of 50mm, 60mm, 70mm and 80mm. The fibre was oven dried at varying temperature of 30ºC, 50ºC 70ºC before further testing.

1) Density Measurement

The fibre densities were investigated for treated and untreated fibres at constant length of 50mm. It was carried out using both Archimedes principle and density bottle measurement.

2) Oven Drying

The fibre was oven dried to achieve 0% moisture content for the fibre. The drying process was carried out using an oven and an electronic weighing balance. This oven was made available at Chemical Engineering Engineering Laboratory, University of Port Harcourt.

3) Tensile Test

The fibres undergo a simple tensile test. The testing was carried out using Tensiometer, the tensile strength of the fibre was measured using the G99-046 Micro Fiber Test Jig. The fibre test specimen is glued at the top and bottom of a cardboard frame. Then the frame is gripped in the test machine. The lower grip is a basic manual vice grip.

3. Results and Discussion

3.1. Density Measurement

The fibre densities were investigated for Untreated and Alkali Treated fibre. The results of the densities are:

1) Untreated Fibre

Density of the bottle without the cover = 18grams

Mass of the density bottle + untreated fibre = 19.50grams

Density = 0.021g/cm^3

2) Alkali Treated Fibre

Density of the bottle without the cover = 18grams

Mass of the density bottle + untreated fibre = 20.00grams

Density of 0.5M (5%) = 0.040g/cm^3

3.2. Oven Drying

It was observed that oven drying temperature suitable for development of the fibre, based on the results temperature of 70°C gave the highest maximum strength of 706Mpa at 80mm fibre length. Therefore, is adopted and accepted as the benchmark for developing the fibre.

3.3. Tensile Strength

Table 3-5 shows results for tensile strength in alkali modified fibre with temperature of 30ºC, 50ºC 70ºC using 10% alkali concentration at varying fibre length were investigated and recorded.

Table 3. *Tensile Strengths on 10% Alkali concentration at 30°C oven bath drying temperature.*

Fibre Replication	Tensile Strengths (Mpa) @50mm	Tensile Strengths (Mpa) @60mm	Tensile Strengths (Mpa) @70mm	Tensile Strengths (Mpa) @80mm
R1	593	480	586	488
R2	556	601	585	682
R3	553	414	452	481
R4	567	498	541	550
R5	520	408	518	508

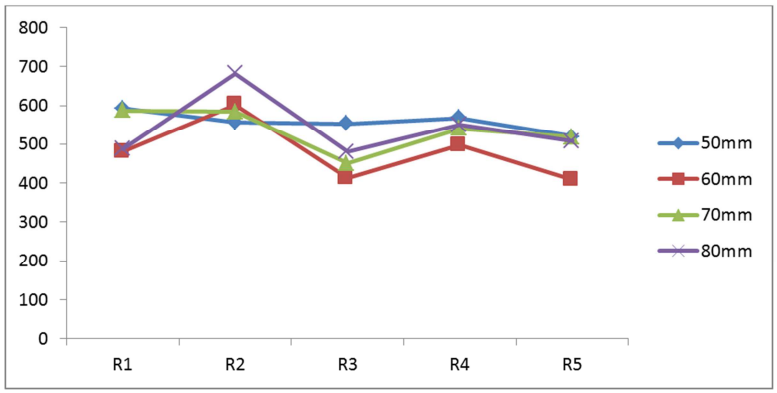

Figure 4. *Graph of strengths for 10% Alkali concentration at temperature of 30°C.*

Table 4. *Strengths for 10% Alkali concentration using 50°C oven temperature.*

Fibre Replications	Tensile Strengths (Mpa) @50mm	Tensile Strengths (Mpa) @60mm	Tensile Strengths (Mpa) @70mm	Tensile Strengths (Mpa) @80mm
R1	689	382	419	523
R2	377	440	459	645
R3	656	389	585	419
R4	574	404	488	529
R5	360	430	550	620

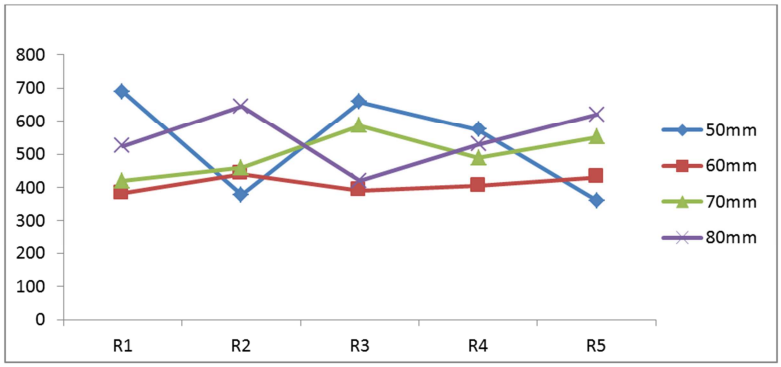

Figure 5. *Graph of strengths for 10% Alkali concentration at temperature of 50°C.*

Table 5. *Tensile Strengths on 10% Alkali concentration at 70°C oven temperature.*

Fibre Replications	Tensile Strengths (Mpa) @50mm	Tensile Strengths (Mpa) @60mm	Tensile Strengths (Mpa) @70mm	Tensile Strengths (Mpa) @80mm
R1	458	487	380	706
R2	456	449	516	601
R3	499	571	560	527
R4	471	502	485	611
R5	409	490	510	625

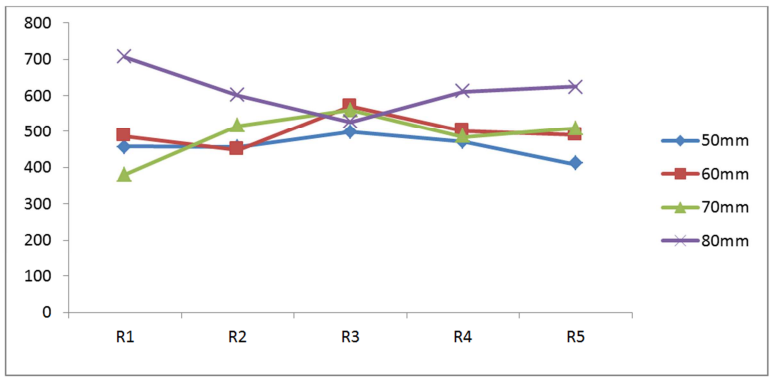

Figure 6. *Graph of strengths for 10% Alkali concentration at temperature of 70°C.*

Table 3-5 and figure 4-6 illustrates the result of alkalization treatment conducted using 10% NaOH concentrations of the solution. The test conducted for strength on the mercerization treated fibres dried at different oven temperature of 30, 50, 70°C using 50mm, 60mm and 70 mm length of fibre. Based on the experimental results, oven temperature of 70°C at 80mm fibre length gave the highest strength of 706Mpa for mercerization treated fibre. At 50°C oven drying temperature gave 689Mpa using 50mm fibre length. At temperature of 30°C gave 682Mpa using 80mm fibre length. The mercerization modified fibre on 10% NaOH concentration at temperature of 70°C gave the optimum highest strength of 706Mpa at 80mm fibre length. Therefore, from the results the 70°C oven bath temperature is therefore adopted and accepted as the benchmark for developing the fibre.

4. Conclusion

Fibers extracted from natural fibre like plantain fibre have a great potential resource for reinforcement because they have better mechanical properties, its abundance and recent status as product from agriculture. Between the hydrophilic natural fibers and hydrophobic polymer matrix is the poor bonding that exists between them which is the major drawback of the fiber-reinforced composites. The aim of this study was to design and develop plantain for application in the production of oil gas facilities. The following process was used to develop the fiber and they include retting, gathering, extraction, processing, oven drying, treated and untreated. The developed fibre is reinforced with plastic after grounding it into particles size to manufacture samples for test which are used to produce oil and gas components like pressure vessel, pipe and piping system among others used in many oil and gas industries.

References

[1] Kabir M. M., H. Wang, K. T. Lau, and F. Cardona, (2012) "Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview," Compos. Part B Eng., vol. 43, no. 7, pp. 2883–2892.

[2] Arpitha G. R, M. R. Sanjay, and B. Yogesha, (2014) "Review on Comparative Evaluation of Fiber Reinforced Polymer Matrix Composites," Adv. Eng. Appl. Sci. An Int. J., vol. 4, no. 4, pp. 44–47.

[3] Jayamani et al., (2014) "The Effect of Natural Fibres Mercerization on Natural Fibres / Polypropylene Composites: A Study of Thermal Stability, Morphology and Infrared Spectrum," *Aust. J. Basic Appl. Sci.*, vol. 8, no. 15, pp. 332–340.

[4] Elenga R. G, P. Djemia, D. Tingaud, T. Chauveau, J. G. Maniongui, and G. Dirras, (2013) "Effects of Alkali Treatment on the Microstructure, Composition, and Properties of the Raffia textilis Fiber," *Bioresour. Peer-reviewed online J.*, vol. 8, no. 2, pp. 2934–2949.

[5] Aziz S. H, and M. P. Ansell (2004), The Effect of Alkalization and Fibre alingnment on the Mechanical and Thermal Properties of Kenaf and Hemp bast fibre Composites: Part I-Polyester resin matrix," composites: Science and technology 64 (9), 1219-1230.

[6] Li, X.; Tabil, L. G.; Panigrahi, S.; Crerar, W. J. (2006) The Influence of Fiber Content on Properties of Injection Molded Flax Fiber-HDPE Biocomposites. CSBE/SCGAB, Edmonton, AB Canada, doi: 10.13031/2013.22101.

[7] Elenga, R. G.; Dirras, G. F.; Goma Maniongui, J.; Djemia, P.; Biget, M. P. (2009) On the microstructure and physical properties of untreated raffia textilis fiber. *Compos. Part A Appl. Sci. Manuf.*, *40*, 418–422.

[8] Fadele, O. E. (2017) Development and characterization of raffia palm fibre reinforced polymer matrix composites. Masters Thesis.

[9] Patrick, C. (2016). A study of chemical treatment and processing for Bananan fibre-reinforced LDPE composites. Master's thesis.

[10] Gibson, The Cost-Effective Use of Fibre Reinforced Composite Offshore Research Group. 2003 Seri Mohd NajibTun, Abdul Razak, Natural Fibre Composite Material Development Energy Sector, 2012.

[11] Faruk O, Bledzki A. K, Fink H, Sain M. (2012) Prog. Polym. Sci. 2012, 37, 1552.

[12] Crawford, R. J. (1998). Plastics Engineering, 3rd edition, Butterworth-Heinemann, oxford Auckland Boston Hopkins, P (2005). High Design Factor Pipelines: integrity issues. Penspen Integrity Units 7-8.

[13] Ihueze, C. C., Oluleye, A. E., Okafor, C. E., Obele, C, M., Abdulrahman, J. and Obuka, S. (2017) Development of Plantain Fibres for Application in Design of Oil and Gas Product Systems. Published in Petroleum Technology Development Journal.

[14] Hopkins, P. (2005). High Design Factor Pipelines: integrity issues. Penspen Integrity Units 7-8.