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CHEMO-PHYSICAL EVALUATION OF SOME TROPICAL SPIDER FIBERS IN SELECTED LOCAL GOVERNMENT AREAS OF BENUE STATE, NIGERIA

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ABSTRACT

Spider fibers, celebrated for its remarkable strength and elasticity, shows great potential in diverse industrial applications, especially in fields like textiles and biodegradable materials. This research examined the mechanical, chemical and physical properties of tropical spider fibers and their potential use in various fields, such as textile manufacturing and biodegradable materials. Through a thorough analysis and comparison of samples collected from three Local Government Areas of Benue State, Nigeria, this study provides valuable insights into the unique properties of these spider fibers and their potential applications. Three different load cells from 1N to 5N and particle sizes of colloidal particles GSP (10mm, 20mm and 30mm) were used varied in 10%, 20% and 30% wt. FTIR, mechanical and physical properties of the spider fibers were evaluated and it shows that spider fiber has excellent structure properties. The FTIR properties include the absorbance and frequency; mechanical properties were tensile strength, flexural strength, modulus of elasticity and stress-strain. The absorption rate of all samples increased with increase in filler content. This was because proactive fibers were formed at the infrared spectroscopy at the mid IR beam line which indicated that fibers less likely to absorb water density generally decreased with increase in force applied on it. This is related to the fact that the spider fiber is light in weight but occupy substantial of toughness. Tensile strength of the fiber increased with increase in reinforcement as a result of treatment from organic compounds Amide. This is so, because smaller particles sizes have higher total surface energy for a given particle and also has more efficient stress transfer mechanism. The results show that the tropical spider fibers studied possess high tensile strength, good elasticity, and unique structural properties, making them highly suitable for use in various industries. This research contributes to the existing knowledge on spider fibers and provides a strong foundation for further research and development in this area. Overall, the findings of this study demonstrate the potential of these spider fibers as a sustainable and versatile material with numerous applications.
Key words: Spider Fibers, Tensile Strength, Tensile Modulus, Chemo-Physical Evaluation, Biodegradable Material

1.0 INTRODUCTION

Spider fibers are abundant natural materials known for their exceptional physical and mechanical properties, making them valuable for various industrial and engineering applications (Chalek and Holland, 2026). These fibers primarily composed of proteins, exhibit remarkable strength, extensibility, elasticity, and biodegradability. Such properties have sparked significant interest in using spider fibers for applications ranging from textiles and aviation to medicine. The lightweight nature and superior mechanical characteristics of spider fibers make them an attractive alternative to synthetic fibers such as Liu *et al.,* (2026) and Numata (2026). Previous research has highlighted the unique capabilities of spider fibers. Olive *et al.* (2026) and Soler and Zaera (2016) explored the potential of spider webs as bio-indicators for monitoring air quality by examining the accumulation of heavy metals like zinc (Zn) and lead (Pb) on spider webs. Their study found that while spider webs could indicate the presence of certain metals, they did not consistently reflect the broader content of these elements in the surrounding dust, suggesting limitations in using spider webs solely for air quality monitoring. Yazawa *et al.* (2019) studied the evolutionary development of spider fibers and webs, demonstrating that the diversification of spiders and their web-making abilities paralleled that of their insect prey, suggesting a co-evolutionary relationship. This evolutionary perspective emphasizes the adaptive advantages conferred by spider web fibers, which have been fine-tuned over millions of years to serve various ecological functions.

Other studies have focused on the mechanical applications of spider webs. Yarger *et al.,* (2018) examined the use of spider web composites with different reinforcement materials, finding that incorporating spider web fibers increased the impact and flexural strength of the composites. Similarly, Su *et al.,* (2018a) highlighted the superior tensile strength and elasticity of spider fibers compared to steel, underscoring their potential in high-performance materials. S Su *et al.,* (2018b) investigated the habitat preferences of web-building spiders, indicating that understanding these preferences is crucial for harnessing spider webs effectively in practical applications. Despite the demonstrated potential of spider fibers, they remain underutilized, especially in regions like Benue State, Nigeria, where they are often considered waste. This study aims to address this gap by conducting a chemo-physical evaluation of tropical spider fibers in selected Local Government Areas of Benue State. By assessing their chemical composition and mechanical properties, such as tensile strength, elasticity, and impact resistance, this research seeks to establish the feasibility of using spider fibers as a sustainable and cost-effective alternative to synthetic fibers.

The need for this study arises from the growing demand for environmentally friendly and biodegradable materials. Natural fibers, including spider fibers, offer advantages over synthetic fibers, such as lower density, non-toxicity, and higher stiffness, which can lead to enhanced energy recovery and reduced material costs. By evaluating the chemo-physical properties of spider fibers and comparing them with other selected natural fibers, this research will contribute to identifying viable alternatives for material production that align with sustainability goals. The findings could pave the way for innovative applications in various fields, including construction, textiles, and biomedicine, thereby unlocking the potential of an otherwise overlooked natural resource.

2.0 METHODOLOGY

2.1 Materials

The materials that were used in this study include: *Malthonica silverstris* web, *ferruginea* web, Kevlar fiber, polyester and nylon. The equipments used for the study are presented in Table 1.

Table 1: List of Materials

Equipment Name	Purpose	Location
Torsion Tester (kawabeta)	Measure the toughness of spider web and other reference coeffi cient variation of fibers	Material Science Unit, University of Nigeria, Nsukka
Micro-tensile tester	Measures average tensile strength	Material Science Labo ratory, ABU, Zaria
Micrometer of co mpound microscope	Measures the deformation of fibers	Material Science Laboratory, UAM
Vibroscope	Measures density of fiber materials	Material Science lab. UAM
Cardboard	To isolate a single strand of fiber	Material Science Lab UAM
Caliper	Measures change in length of the fiber trend	Material Science Lab. UAM
Powellscope ASTMD 38 22	Measure the diameter of fiber	Material Science Unit, University of Nigeria, Nsukka
Tensile test device	Measures tensile strength of fiber	Material Science Unit, University of Nigeria, Nsukka
Raman Spectroscope	Measures the vibration of frequency on fibers	Material science Lab. ABU, Zaria
MTS Criterion Model 42 Tensile Tester	Measures the stress and strain of fibers	Material science Lab. ABU, Zaria
Magna-T Frame	Measures force and distance	Material Sc. Lab. ABU, Zaria

2.2 Method

The study was conducted on spider webs from the forests and vegetation of Benue State, Nigeria (Latitude 6° - 8.1°N and Longitude 7.44°E - 9.55°E). Specific sites included Vandeikya, Kwande, and Makurdi local government areas, which feature both subtropical and tropical savannah-type forests. The choice of Ferruginea and Malthonica silvestris webs was due to their archetypal appearance and geometric properties that facilitate modeling.

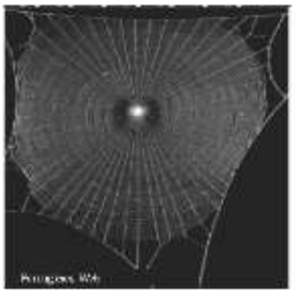


Figure 1: Morphology of *Ferruginea* Web
Figure 2: Morphology of *Malthonica Silvestris* Web

Spider webs were then collected from the specified forest areas for evaluation against other reference fibers. The webs were isolated onto microscope slides and secured to prevent contamination. Focal microscopy and Raman spectroscopy were utilized to study the fibers' morphology and chemical composition as shown figures 1 and 2. Fiber samples for spectroscopy were embedded in epoxy resin, sectioned, and mounted for analysis. A dilute sulfuric acid solution simulated exposure to acid rain, investigating its impact on the fibers' structure. A 0.001 M sulfuric acid solution was prepared to simulate environmental conditions that could affect spider webs in natural settings. The study explored the impact of acid rain exposure on the structural integrity of spider fibers.

The flexural strength test was performed using a 50ks capacity Torsions universal testing machine, adhering to ASTM A-790 (ASTM, 2018) standards, with a 3-point bending fixture. Sample dimensions were 100mm x 30mm x 5mm. The Modulus of Rapture and Modulus of Elasticity were calculated using equations 1 and 2 respectively.

$$M_{or} = \rho l/(2bt^2)\ (mPa) \qquad (1)$$

$$M_{oe} = (\rho l)^3/(4bt^3 T)\ (mPa) \qquad (2)$$

Where, ρ is max force applied on test specimen (N), L is the gauge length (mm) B is the width of the specimen (mm), T is thickness of the specimen mm, Y is the deflection.

The tensile strength, tensile modulus and percentage were calculated using equation 3, 4 and 5.

$$\text{Tensile strength} = \rho/bh \quad (3)$$

$$\text{Tensile modulus} = \partial/\varepsilon \quad (4)$$

Where, ρ is the pulling force (N), b is the specimen with (mm), h is the specimen thickness (mm), ∂ is the stress (mpa), ε is the strain

$$\text{Percentage elongation at fracture} = E/L \times 100\% \quad (5)$$

Where E is the elongation and L is the original length.

The effect of stress on the molecular structure and mechanical properties of spider fibers was investigation in accordance with ASTMD 570 – 98 (ASTM, 2018), using FTIR spectroscopy: The preliminary experiment was performed on beam line U4 at (NISLT) Nigerian institute of science Laboratory Technology Zaria, Kaduna State Nigeria, most of the data collection was performed at Beamline BLOIBI. FTIR spectra were recorded using a Nicolet 6700 FTIR spectrometer with a liquid Nitrogen cooled detector couple with a Nicolet contain micro meter microscope with a 32x objective at 250C. For each measurement, 256 interferogram were co-added and transformed employing a Genzel. Happ, apodization function to yield spectra with a normal elastic resolution of 4cm-1. Deconvolution of the amide III band (1265cm-1) for spider fiber, 1224cm-1 for polyester, and 1235cm-1 Gaussian model was selected for the band shape, and the bandwidth was automatically adjusted by the software. The orientation of certain spider fiber was obtained from the angular dependence of the absorbance. A (v) at wavelength V which corresponds to a vibration of the molecular structure group under investigation.

In the general case, the angular dependence of the absorbance was been determined using the following function (ASTM, 2018).

$$A(V,\Omega) = -\log_{10}\{10^{(A_{max}(v)).(\Omega-\Omega_o)} - A_{min}(v)\cos^2(\Omega-\Omega_o)\} \quad (6)$$

Where A (V, Ω) is the peak intensity of a curtained band, Ω is the polarization angle, Ωo is the angle at maximum absorption of fiber, Amax and Amin are the maximum and minimum absorbance respectively. The molecular band structure parameter (Smol) of the corresponding structural fiber was calculated as follows:

$$S^{mol} = (A_{max}(v) - A_{min}(v))/(A_{max}(v) + 2A_{min}(v)) \quad (7)$$

The theoretical boundary values of Smol+ 1 and 0.5, which correspond respectively to perfectly parallel and perfectly perpendicular with respect to the fiber axis.

The tensile properties were measured using a micro-force transducer setup that applied a controlled force to the fiber strand and measured deformation via a microscope. Calculations of stress, strain, and modulus of elasticity used standard equations to determine the mechanical properties of the spider fibers. Dynamic mechanical analysis (DMA) was performed using a dynamic mechanical analyzer calibrated to ASTM standards. The DMA provided data on the storage modulus and other mechanical properties by subjecting fibers to controlled stress conditions. Physical evaluation involved mounting individual fiber strands onto frames using epoxy resin, ensuring alignment and consistency in testing. A tensile test was conducted by applying gradual elongation and measuring the resulting force-displacement response.

3.0 RESULTS AND DISCUSSION

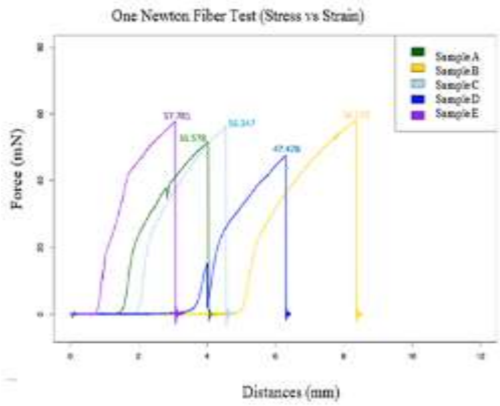

Figure 3: Effect of Force and Distance on Spider and other Reference Fibers

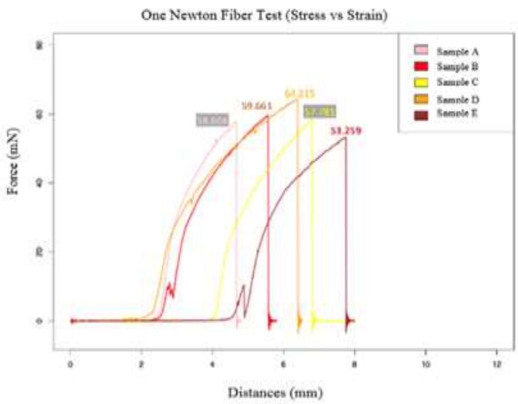

Figure 4: Effect of Force and Distance on Spider and Other Reference Fibers

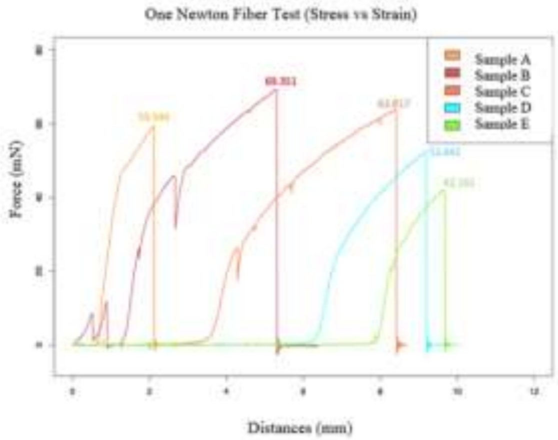

Figure 5: Effect of Force and Distance on Spider Fibers

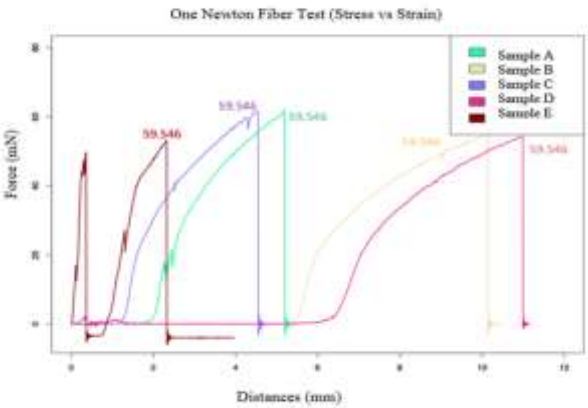

Figure 6: Effect of Force and Distance on Spider Fibers

All samples were studied using Tensile tester device but only the Malthomica silvestris and polyester fiber were analyzed with STXM beamline due to time constraints with the use of FT-IR spectroscopy at the Mid IR beamline, absorbance and frequency spectra were recorded. The force versus distance data was split up into five (5) samples each, totaling 3 separate plots. Each sample is color coordinated, using a unique color for each sample test, but using that same color for the corresponding results in the stress Vs strain required to deform the spider fibers and the delayed restoration in the other test on criterion Model 42 Tensile tester device. The force Vs distance plots are in millimeters and millinewtons. Millinewtons were used because they provided the most insight on the data, with values starting at 0± 0.024mN and breaking between 40=˜60mN. The plots are presented in Figures 3-6. Table 3 was a summary of all the tests max stress force applied before breaking in millinewtons. The average breaking force was 42.912mN ±6.137.

Table 3 summarizes the data for the force and distance graphs at which the fiber started experiencing stress and deformation length where the fiber broke, the total distance travelled is the total length the fiber were under tension. The last column is the force converted to Newton, which was used later on in the stress Vs strain conversions. This agrees with the work of Blamires *et al.,* (2017). It observed that the physical properties of a fiber such as, force and distance increased as the filler load cell increase

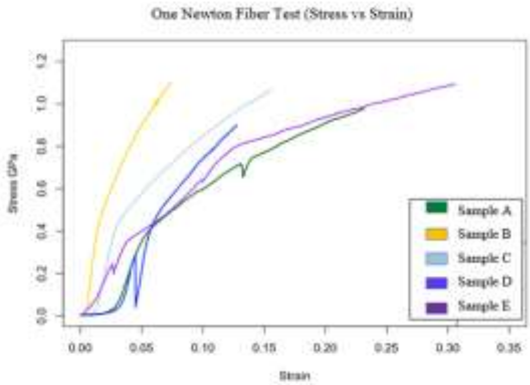

Figure 7: Effect of the Stress Required to Deform Spider Fibers and Delayed Restoration Strain

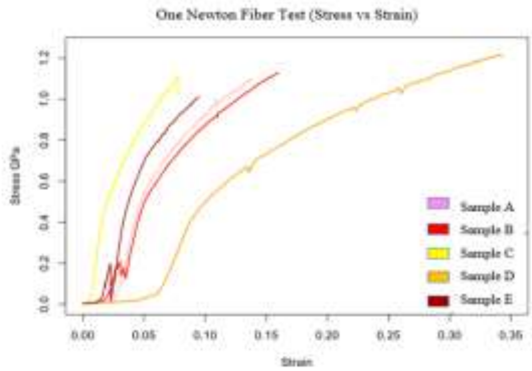

Figure 8: Effect of the Stress Required to Deform Spider Fibers and Other Reference Fibers

The computed stress and strain values of spider fibers, Kevlar fiber, Maithomica silvestris fiber, polyester and nylon are shown in Figures 7 and 8. It presents the relationship between stress and strain of spider fiber and other reference fibers at five properties size variations (1N, 2N, 3N, 4N and 5N). The effective start length varies greatly between samples for multiple reasons. When mounting the samples, there was 10mm gap that the fiber laid across. It observed that the stress and strain increased is due to the ability of force exalted or applied on spider fibers. It also clearly indicates that in conclusion, spider fibers improved the load bearing capacity of the reference natural fiber. The higher the tensile strength of spider fiber value was as a result of the capability of the thread, sustains stresses transmitted from other fibers. This is in conformity with the work of Usman *et al.,* (2016) on the mechanical characteristics of natural fiber particles reinforced nanofiber.

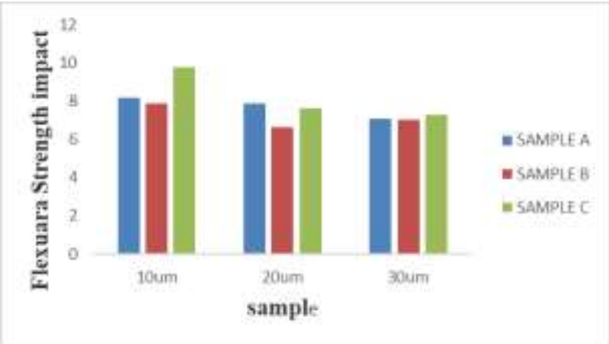

Figure 9: Effect of Flexural Strength on Spider Fiber

The values of modulus of rupture of the samples are shown in Figure 9. It represents the flexural strength on spider fiber and other reference fibers, at ≤ 30mm. Increase in flexural strength on fiber resulted in increase in modulus of rupture. This was also stated by Lefèvre and Auger (2016) in their study of natural fiber parties. Results showed that flexural strength and modulus of elasticity treated fibers increased with increase force applied on microscope slider beam. This is caused by the enhancement of interfacial adhesion induced through surface modification. The highest flexural strength was recorded as 10.1% GSP which was Kerlat fiber beyond this point, there was a decrease in other reference fibers. This decrease can be attributed to weak filler matrix adhesion and insufficient filler content. In accordance with this Salmah *et al.,* (2012) in the study on preparation and testing of composite using coir fiber stated that the flexural strength of fiber decreases with increase in the grain size from 1 to 1.5 and then further increases with increase in the size from 1.5 to 2.0.

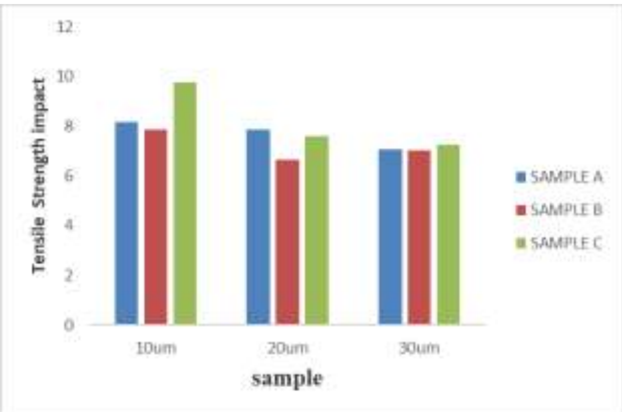

Figure 10: Effect of Tensile Strength on Spider Fiber and Other Reference Fibers

The result of tensile strength test on spider fibers and other reference fibers is presented in Figure 10. It presents the relationship between tensile strength test on spider fiber and other reference fibers at three properties size variations (≤ 15N, 10N and 5N) and three variations (30mm, 20mm and 10mm). It shows that the tensile strength of the spider increases with increase force applied on it. This agrees with the work of Lefèvre and Auger (2016) and Xu *et al.,* (2014) which observed that the tensile strength of sample fibers treated increase as filler content increased. The increase of tensile strength is due to the ability of force application. This is related with the work of Naidu *et al.,* (2013) which forced on mechanical characteristics of natural fiber particle reinforced nanofiber. It shows from the result obtained that, tensile strength of spider fiber is higher in highest at 0.9 MPG. This was attributed to the surface treatment, which promoted the ability and better fiber adhesion. Thus, this allows for efficient stress transfer between other fibers.

Also, from the work of Nakata (2012), the ultimate tensile strength of GSP recycled composite materials for five samples were studied. Tensile strength of the samples increased as a result of treatment of fibers (particles). Smaller particles size had the highest tensile strength. In the same vein, (Raju *et al.,* (2012) studied the mechanical and physical characteristics residue responsible for the increase in tensile strength. However, at some point of further increment in the filler content, a decrease in the tensile strength was witnessed. As the fiber loading increases, the degree of obstruction increases, which in turn decreases the strength of the samples. Smaller particles have a higher total surface energy for a given particle loading. Tensile strength increases with increasing surface area of the fiber particles through more tensile strength transfer mechanism (Tiwana *et al.,* 2012).

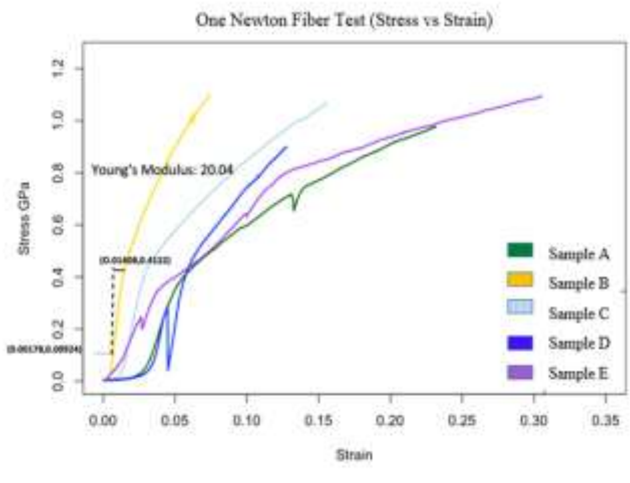

Figure 11: Effect of Young Modulus on Elasticity of Spider Fibers

The result of modulus of elasticity on spider fiber is presented in Figure 11. The modulus of elasticity was evaluated from stress-strain curve close to 0, from Figures 15. By taking the slope of the linear region of the stress-strain, we found an average young modulus of 11.187Gpa± 6.498Gpa. This is compared to the accepted modulus of Mori fiber of 7Gpa [20]. These fibers demonstrated a variability in experimental values across many groups (Aoyanagi, Y and Okumura 2010). The ranging difference in these elastic modulus values could potentially be explained by the difference in cross sectional area both within our experiment and fro other groups. Another observation from the stress-strain curves produced was that they visually behave like previous stress-strain of Mori fiber (Aji *et al.,* 2007).

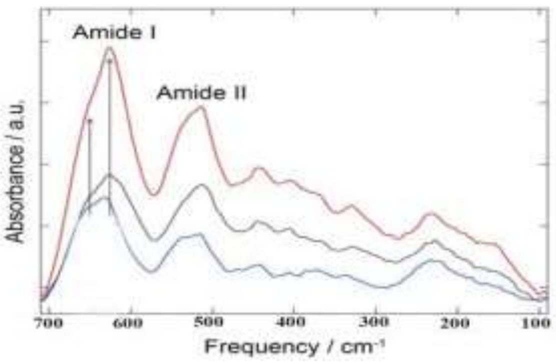

Figure 12: Effect of Absorbance and Frequency Spectral on Spider Fiber and Reference Fibers

Five samples were studied using the Mid IR beamline but only Kevlar fiber, Malthomica servestris fiber and nylon were analyzed with STXM beamline due to time constraint with the use of FT-IR spectroscope at the Mid IR beamline, we recorded frequency and absorbance spectra. There were two primary properties in the spider fiber infrared spectrum, one was Amide I band which falls into the range of 600-700cm1 and the other Amide II band falls into the range of 500-600cm1. The representative spectra effect on spider fibers is shown in Figures 12-13.

Particular interest goes to the Amide I band which was primarily determined by fiber deformation. It was not discern any peak in the Amide I and Amide II region of the untreated and acid treated, Malthomica seritris and the Formginea wed samples Figures 11-12. Both fibers were still presented and it appears from this structure of the two samples we had predicted that a fracture in the fiber structure could have been caused by the denaturation of fiber structure due to the organic compound Amide exposure to cause a chemical change in the composition of the fibers.

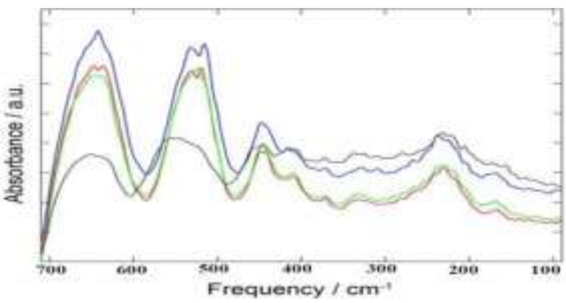

Figure 13: Effect of Absorbance and Frequency Spectral on Spider Fiber and Other Reference Fibers

4.0 CONCLUSION

This study examined the chemo-physical properties of tropical spider fibers in Benue State, Nigeria. The spider fibers along with other reference fibers showed satisfactory mechanical and physical properties including tensile strength, force/distance, stress/strain, flexural strength, and modulus of elasticity. These properties were particularly good in samples produced with a 1N load cell and 30mm GSP composition. The stress required to deform the spider fibers and the delayed restoration strain were also satisfactory, with the best results seen at a 40mN GSP composition. Detailed information about the morphological structure and other properties of the fibers was obtained through focal microscopy and Raman spectroscopy

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