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Mechanical Properties of Enset Fibers Obtained from Different Breeds of Enset Plant

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Abstract**—**Enset fiber is agricultural waste and available in a surplus amount in Ethiopia. However, the hypothesized variation in properties of this fiber due to diversity of its plant source breed, fiber position within plant stem and chemical treatment duration had not proven that its application for the development of composite products is problematic. Currently, limited data are known on the functional properties of the fiber as a potential functional fiber. Thus, an effort is made in this study to narrow the knowledge gaps by characterizing it. The experimental design was conducted using Design-Expert software and the tensile test was conducted on Enset fiber from 10 breeds: Dego, Dirbo, Gishera, Itine, Siskela, Neciho, Yesherkinke, Tuzuma, Ankogena, and Kucharkia. The effects of 5% Na-OH surface treatment duration and fiber location along and across the plant pseudostem was also investigated. The test result shows that the rupture stress variation is not significant among the fibers from 10 Enset breeds. However, strain variation is significant among the fibers from 10 Enset breeds that breed Dego fiber has the highest strain before failure. Surface treated fibers showed improved rupture strength and elastic modulus per 24 hours of treatment duration. Also, the result showed that chemical treatment can deteriorate the load-bearing capacity of the fiber. The raw fiber has the higher load-bearing capacity than the treated fiber. And, it was noted that both the rupture stress and strain increase in the top to bottom gradient, whereas there is no significant variation across the stem. Elastic modulus variation both along and across the stem was insignificant. The rupture stress, elastic modulus, and strain result of Enset fiber are 360.11 ± 181.86 MPa, 12.80 ± 6.85 GPa and 0.04 ± 0.02 mm/mm, respectively. These results show that Enset fiber is comparable to other natural fibers such as abaca, banana, and sisal fibers and can be used as alternatives natural fiber for composites application. Besides, the insignificant variation of properties among breeds and across stem is essential for all breeds and all leaf sheath of the Enset fiber plant for fiber extraction. The use of short natural fiber over the long is preferable to reduce the significant variation of properties along the stem or fiber direction. In conclusion, Enset fiber application for composite product design and development is mechanically feasible.

Keywords**—**Agricultural waste, chemical treatment, fiber characteristics, natural fiber.

I. Introduction

DEMAND for sustainable lightweight materials and economic factors in many developing countries, where natural fibers are surplus but unused, push for means to utilize natural fibers effectively for different applications such as composite structure. The incorporation of natural fiber from agricultural waste will make this active area of R&D more fascinating [38], [41], [18]. This is dual-purpose, since these wastes can generate economic benefits when used for different useful applications which can enhance the sustainability of farming of related crops that in turn will ensure food security. Natural fibers are favored over synthetic fibers by engineers, researchers, professionals and scientists all over the world as an alternative reinforcement, because of its superior properties such as high specific strength, low weight, low cost, fairly good mechanical properties, nonabrasive, eco-friendly and bio-degradable characteristics [9]. They come from abundant and renewable resources, which ensures a continuous fiber supply and significant material cost savings to the plastics, automotive and packaging industries [27]. The natural fiber may be wood, sisal, hemp, coconut, thread, kenaf, flax, jute, abaca, banana leaf fibers, bamboo, wheat straw or other fibrous material that are used as reinforcement due to their good mechanical properties [41], [39]. The use of natural fibers reduces weight by 10% and lowers the energy needed for production by 80%, whereas the cost of the component is 5% lower than the comparable fiberglass-reinforced component [28]. These natural fiber composite materials are being increasingly used in the automotive and building industry but estimated to only 10% of the potential of these fibers [38], [39]. However, natural fiber composites have the highest specific performance per price than other materials such as steel, aluminum and FRP [24]. However, the use of natural fibers has few setbacks such as variation of properties, poor compatibility with matrix, high moisture absorption and lower thermal stability. To overcome such setbacks, natural fibers are subjected to surface modifications such as alkali treatments [30]. Overcoming the setbacks, with their unique and wide range of variability, natural fiber composites could emerge as an alternative engineering material that can substitute the use of synthetic fiber composites, not only for non-load bearing construction elements but also for structural elements [44].

The property of the fiber is very important in determining the properties of the composite [16], [22], [33]. Accordingly, the research to determine the properties of natural fiber is crucial in investigating the properties and understanding the possible variation of the properties.

The property of natural fiber is a function of the properties of plant cell walls. The plant cell wall is long believed to be composed of two separate networks: a pectin network and a

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hemicelluloses/cellulose network [14]. Pectin [32] and cellulose [37] are the main load-bearing cell wall structures. Reference [35] emphasizes the interactions of the two networks that pectin and cellulose interactions strengthened as the stem matured and growth diminished. However, in a top to a base gradient, the pectin amount decreases, and the cellulose and xyloglucan amount increases. As a result, viscoelastic compliances along the stem (plastic and elastic compliances (fractional strain per unit of force; reciprocal of stiffness) decrease in a top to a base gradient. So, these works show that cellulose and pectin, as well as their interactions, are important in load-bearing.

The natural fiber plant of choice in this study is Enset (*Ensete ventricosum*) crop plant which is a perennial monocarpic plant belongs to the family Musaceae. The crop is widely grown in southern Ethiopia on 301, 978.68 hectares of land mainly to produce a starchy food from its vigorous pseudostem, corm, and stem of an inflorescence. It plays a great role in the food security of the country and a staple food for more than 20% of Ethiopia's population [1]. Two-third of this plant is located in the Southern Nations, Nationalities and Peoples Regional State [SNNPRS] and one-third is located in Oromia [15].

From this coverage of the Enset plant, there are surplus resources of agricultural wastes (by-products) called Enset fiber which was not used efficiently and widely [38], [45]. Enset fiber at present is the main byproduct resulting from decortications of the pulp from leaf sheaths of the pseudostem of the Enset plant. Hence, without including the additional cost for input, it can be obtained simply for manufacturing purposes. But, the know-how in using Enset fiber is not much matured in Ethiopia that it could not be seen as an alternative to the synthetic fibers and other natural fibers. This may be for the fact that most previous research works on Enset dealt with food components and, chemical and physical properties [2]-[4], [29], [31]. However, there are promising limited works on Enset fiber which give insight that it can be used as an alternative to synthetic and other natural fibers [1], [10]-[13], [47]. On the other hand, in these previous studies on Enset fiber, variation in fiber quality among different Enset plant breeds was not considered but the work on the food components indicates its existence [46]. The difference in tensile strength of the Enset fiber sampled from different locations (probably of different breeds) strengthens this point of variation in fiber quality among different Enset plant breeds [10], [23]. Also, the influence of factors such as surface treatments with varying treatment duration is not clearly stated. For Enset fiber to be one of the most important fibers such as jute, abaca, flax, sisal, hemp, and coir for composite manufacturing, more work is expected from the researchers in investigating the properties of the Enset fiber in-depth and comparing its strength with other synthetic and natural fibers.

Consequently, in this study, mechanical and physical properties characterization of Enset fiber was focused [20]. The experiment was designed by Design Expert Software [Version: 11.0.3.0] to conduct mechanical property tests such as tensile tests [27]. Also, measurements of Enset fiber physical property such as diameter, density, and moisture content were conducted. The results of this study will contribute to locally build lightweight Enset fiber-reinforced composite and employment opportunities of the people in mass production of the Enset fiber for commercial activity.

II. Material and Methods

A. Material

Enset fibers are selected from three zones Gurage (Agena site), Kembata (Serera site) and Wolaita (Areka site) located in SNNPRS of Ethiopia, which are rich in Enset varieties. For ease of handling, 10 breeds: Neciho and Yesherkinke of Agena, Dirbo, Siskela, Gishera, Dego and Itine of Serera and Ankogena, Kucharkia and Tuzuma of Areka are selected based on local farmer's suggestion for relatively good food component and fiber yield, see Fig. 1. The sites are at altitudes ranging 1800-2800 m, temperature 10-25 °C and annual rainfall 1000-1800 mm.

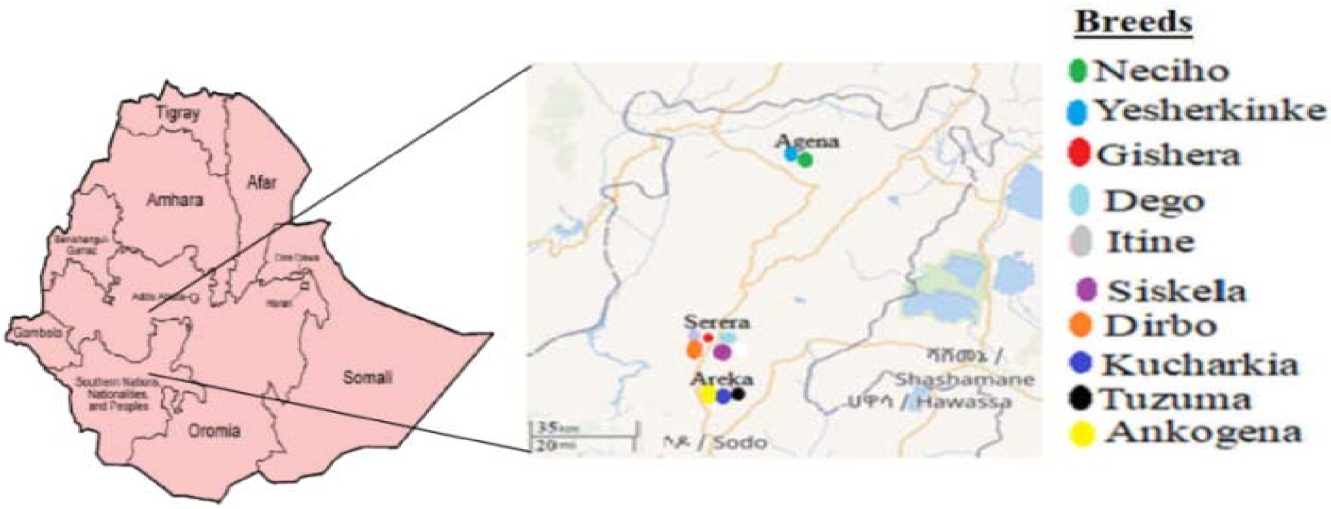

Fig. 1 Sample site [19]

For test specimen preparation, epoxy 2301 and hardener 2301/50 supplied by Resinpal, Germany was used as adhesive to bond paper tap with fiber. And, 5% Na-OH solution supplied by Carl Roth GmbH. Co. KG, Germany was used for chemical treatment.

B. Methods

1. Design of an Experiment

The study focused on mechanical and physical properties characterization of Enset fiber to utilize it as alternative natural fiber [20]. The effects of four factors: breeds with ten levels, chemical treatment durations with four levels, fiber location along the stem with three levels and fiber location across the stem with three levels, are considered. And, an experiment consisting of 56 runs each with five repetitions was designed using Design Expert Software [Version: 11.0.3.0] to investigate properties of 10 different Enset fiber breeds.

2. Enset Fiber Extraction

Fig. 2 Fiber position across the stem

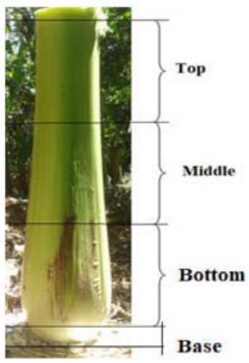

Fig. 3 Fiber position along the stem

The Enset fiber was extracted from the pseudostem part of the Enset plant by using hand decortications [8], the stem is built with several layers of sheathes of thickness 20-40 mm range which is tightly overlapped. After dismantling and sorting as per fiber position across plant stem from outer to the core as outer, middle, inner and core on average 100 mm gaps from each other was performed, Fig. 2. The core was soft and not used for fiber extraction. The pulpy tissues were scraped out, traditionally, by using a sharp-edged bamboo against flat wood along the fiber length. Then, the fibers were tied at the base with labeled textile for ease of further sorting along the plant stem from bottom to top as the bottom, middle and top on average 300 mm gaps from each other, Fig. 3. The bottom is 200 mm from the base on average. The fibers were then sun-dried in the open air for 3 to 5 days.

3. Fiber Chemical Treatment

Natural fiber, plant cell wall, is believed to be composed of a pectin network and a hemicelluloses/cellulose network [14]. Pectin [32] and cellulose [37] are the main load-bearing components. However, the strength and integration of these components can be affected by chemical treatment. Therefore, to investigate the effect of alkali treatments on properties of the Enset fiber, 30 grams of Enset fiber was prepared and soaked in 700 ml of 5% Na-OH solution for 0 h, 2 h, 24 h and 48 h at room temperature. And, then, it was immersed in distilled water for 24 h and washed thoroughly in distilled water to remove the excess Na-OH and dried at 60 °C for 24 h. Final washing was done with distilled water [7], [17], [36], [40]

4. Experimental Test

Primarily, physical parameters such as fiber diameter, linear density, true density, and moisture content were measured for Enset fiber. Test specimens were prepared by bonding the fiber with paper tab using epoxy and hardener from Resinpal, Germany with a 2:1 mixture ratio. Then, the tensile test was conducted by exposing the specimen to the uni-axial tensile load. During the test, to reduce the varying effect of the environment, all test trials took place at 20 °C and 30% relative humidity.

i. Physical Properties Measurement

An optical microscope (Leica EZ4 HD, Germany) was used to measure the diameter of Enset fibers using a stage micrometer of 2 mm length and 10 μm scales. The single fiber was placed on a stage micrometer glass slide and diameter was measured at five points, and the average was taken [35]. Fiber linear density was determined according to the gravimetric method based on the ASTM test method D 1577. The standard length (L) in meters of a specimen with N number of individual fibers was cut and weighed to get the weight (W) in grams of fibers. The average linear density (D) in denier of individual fibers was calculated, (1):

$$D = \frac{9000W}{L.N} \qquad (1)$$

The Archimedes (Buoyancy) method was used to measure the true density of Enset fibers for its simplicity and low cost. The sample, a bundle of fibers, was weighed in air and then in canola oil that was used to wet the sample and it had smaller in density than the sample. The difference of the two media was the buoyancy force. The weighing process was conducted on an analytical balance with a resolution of 0.0001 g and was adapted for suspension weighing through the attached stainless rod. The buoyancy force was converted to sample volume by dividing the liquid density. The sample density ρf was acquired by dividing sample weight in the air with sample volume, (2) [ASTM-D3800–99, 2005]:

$$\rho_f = \frac{(M_3 - M_1)\rho_l}{((M_3 - M_1) - (M_4 - M_2))} \qquad (2)$$

where ρ_l is the density of liquid, M_1 weight of suspension wire in air, M_2 the weight of suspension wire in liquid (to immersion point), M_3 the weight of suspension wire plus item whose density was to be determined in air and M_4 weight of suspension wire plus item whose density was to be determined in liquid. Five fiber samples were tested for each immersion liquid [26]. And, a measurement of moisture was made by Infrared Moisture Analyzer (Sartorius MA35, Germany), (3):

$$Moisturecontent(\%) = \left(\frac{Watermass}{Totalmass}\right) * 100 \qquad (3)$$

ii. Tensile Testing

The tensile test was performed on single Enset fiber by exposing to uni-axial load in order to find tensile strength, according to ASTM D3379-75 with test specimen fastened as shown in Fig. 4. A computer-controlled tensile testing machine with a 5000 g load cell using the full-scale load of 50 N at the cross-head speed of 0.2 mm/s was used in laboratory, Kassel University, Germany. The fiber gauge length is set to 25 mm and the grip length is 10 mm.

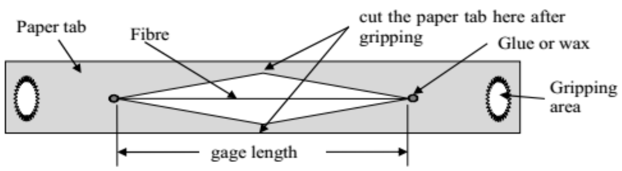

Fig. 4 Method of fasting of the fibers to the tensile test [5], [34]

III. Results and Discussion

Load and elongation data of each test specimen under uni-axial load were primary data generated by the computer attached to the testing machine. The secondary data like stress, strain and elastic modulus were derived from these primary data. The results of the measurements were statistically evaluated by Analysis of Variance (ANOVA) using Design-Expert Software (Version11.0.3.0). The effects of the factors and interactions were separated and tested for statistical significance. The typical stress-strain plot of Enset fiber under uni-axial load showed that stress is directly proportional to strain up to 0.01strain but as loading continues proportionality will not work and Enset fiber fails sharply at rupture force, Fig. 5.

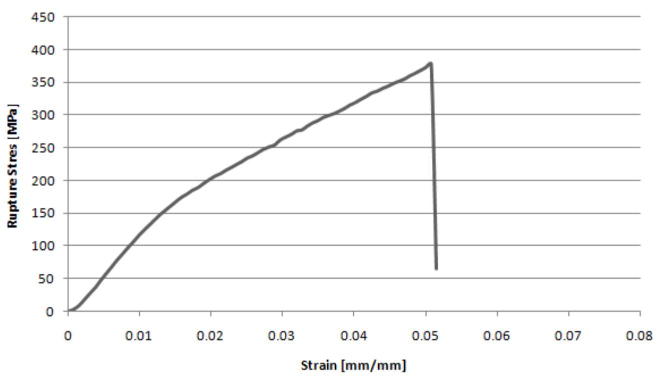

Fig. 5 Typical stress-strain plot of Enset fiber under uni-axial load

Enset fiber diameter is 166 ± 46 µm which is in the same range as sisal, abaca and banana fibers [21], [25], [42]. However, the density of 0.9 ± 0.18 makes it the fiber of the highest specific strength compared to sisal, abaca, and banana [6], [25], [42].

A. Rupture Force

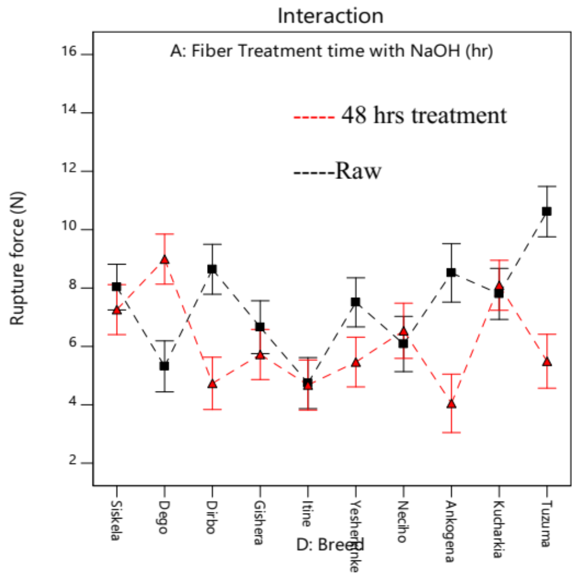

Fig. 6 Rupture force against treatment and breed

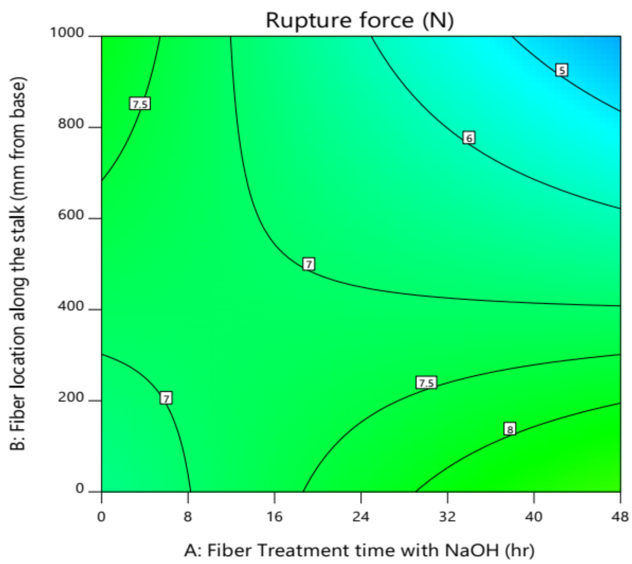

Fig. 7 Rupture force against treatment and fiber location along stem interaction

As depicted in Fig. 6, the rupture force can be influenced by breed-chemical treatment interaction. The test result shows that the variation of the rupture force is significant among 10 Enset fiber breeds where raw fibers from breed Tuzuma, Ankogena, and Dirbo have a higher similar maximum rupture force than other breeds. Also, the result showed that chemical treatment can deteriorate the load-bearing capacity of the fiber that 60%, 30% and 10% of the treated breeds showed poor, similar and higher rupture force, respectively. And, it was noticed in Fig. 7 that for fiber exposed to more treatment durations, the pectin-rich top fiber region is more susceptible to chemical-degradation and becomes weaker whereas the bottom fiber showed slightly become stronger due to high cellulose content at the bottom [35]. This is due to the solubility of the galacturonic acid-Pectin main content in the alkali solution is higher at Pectin-rich top region. Whether treated or not, rupture force variation across the stem is insignificant that it is promising to have increased fiber volume, Fig. 8. The average rupture force of Enset fiber is 6.88 ± 2.7 N.

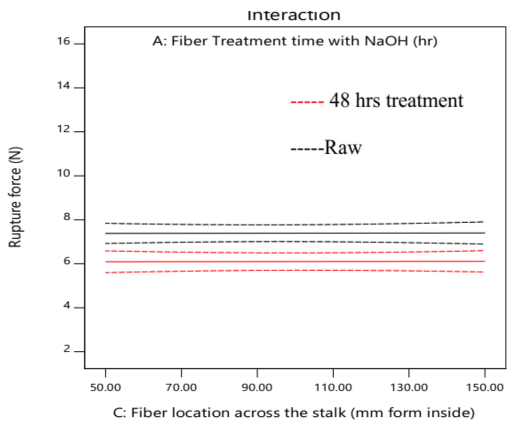

Fig. 8 Rupture force against treatment and fiber location across stem interaction

B. Strain

Strain variation is dominant against breeds that breed Dego has the highest strain, see Fig. 9. Also, the result showed that chemical treatment can improve the elongation of the fiber that 70% of the treated breeds showed a higher strain. And, it was noticed in Fig. 10 that strain increases in the top to a bottom gradient. Also, for fiber exposed to more treatment durations, like the rupture force, the pectin-rich top fiber region is more susceptible to chemical-degradation and fails shortly whereas the bottom fiber elongates more due to high cellulose content at the bottom [35]. And, there is no significant variation across the stem. The average strain of Enset fiber is 0.04 ± 0.02 mm/mm. Enset fiber strain is comparable with that of banana and abaca [6] and sisal [43].

C. Rupture Stress

The test result shows that Enset fiber from deferent breeds has similar rupture stress and the variation is not significant, as shown in Fig. 11. Even if not significant, breed Kuckarkia has relatively highest rupture stress. However, it is evident that all treated breeds showed improved rupture stress than the raw one. Besides, the 24 h treatment duration made better improvement in rupture strength, before and after which the stress declines, Fig. 12. Similar to rupture force, rupture stress across the stem is insignificant that it is also good news to have increased fiber volume. Including all breeds, the average rupture stress of Enset fiber obtained in this study is 360.11 ± 181.86 Mpa. This value is almost in agreement with and by far less than the tensile strength reported by [28], [10], respectively.

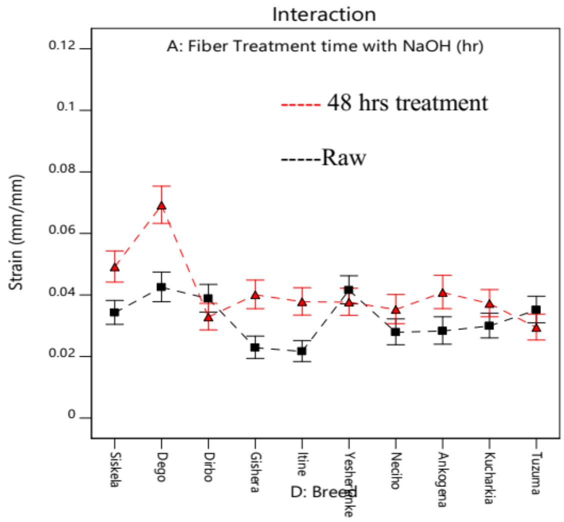

Fig. 9 Strain against treatment and breed

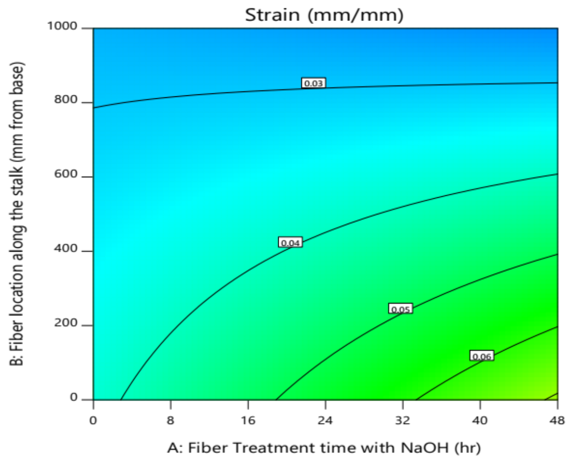

Fig. 10 Strain against treatment and location along the stem

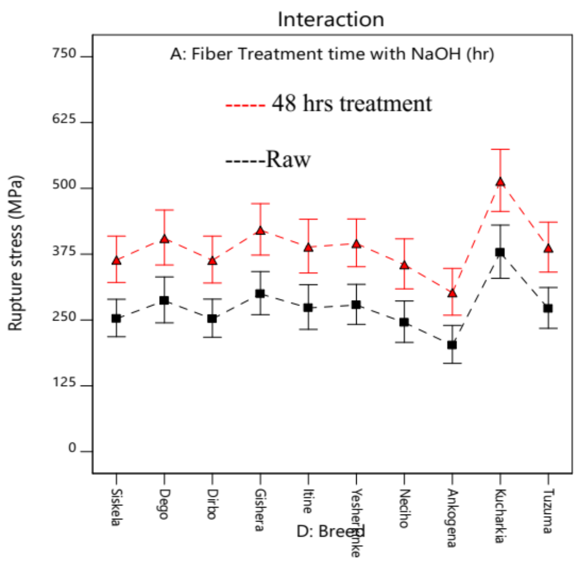

Fig. 11 Rupture stress against treatment and breed

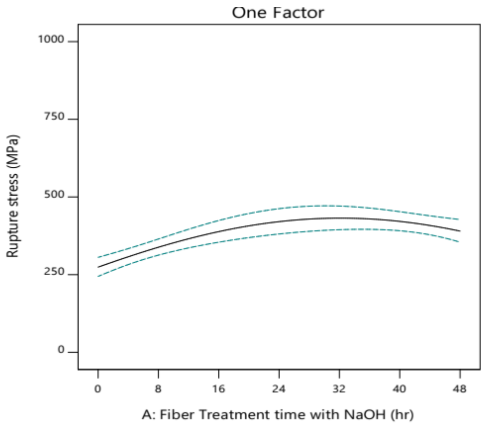

Fig. 12 Rupture stress against treatment

D. Elastic Modulus

Similar to rupture force, as shown in Fig. 13 that the variation of the elastic modulus is significant among 10 Enset fiber breeds where breed Kuckarkia, Gishera, and Itine have higher similar maximum elastic modulus than other breeds. Also, it is evident that all treated breeds showed improved elastic modulus than the raw one. Besides, like rupture stress, the 24 h treatment duration made better improvement in elastic modulus, before and after which the stress declines, see Fig. 14. Also, elastic modulus variation both along and across the stem is insignificant. The average elastic modulus of Enset fiber is 12.80 ± 6.85 GPa. This value is within the same range of elastic modulus of sisal [6] and abaca [42], [43] which shows that Enset fiber can be alternative to sisal and abaca for applications requiring the similar stiffness.

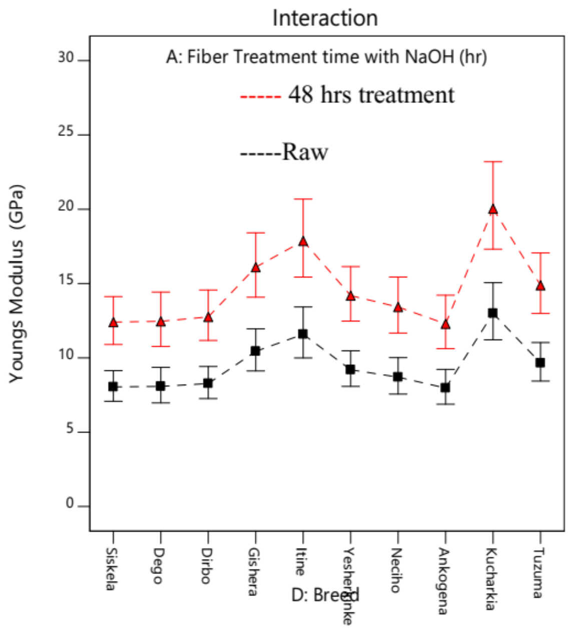

Fig. 13 Young's Modulus against treatment and breed

Rupture force and strain increase in a top to the base gradient. However, the rate of increase of rupture stress and strain was not reflected on young's modulus due to either the slight increase in fiber diameter in a top to base gradient or the rate of increase is equal. That is why the stiffness variation is insignificant in a top to base gradient contrary to what was reported for growing plant cell wall [35].

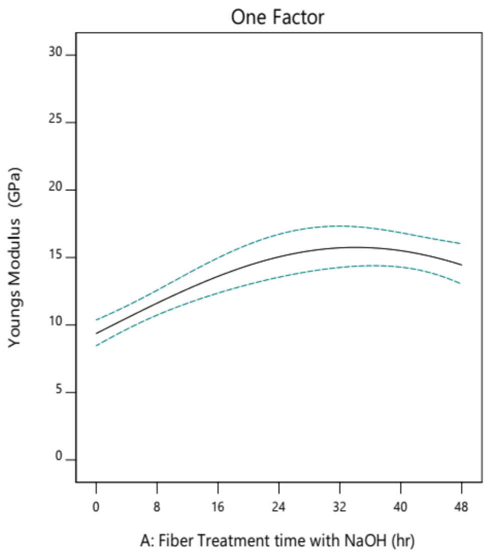

Fig. 14 Young's Modulus against the treatment

E. Effect of Treatment Duration on Rupture Force, Strain, Stress, and Elastic Modulus

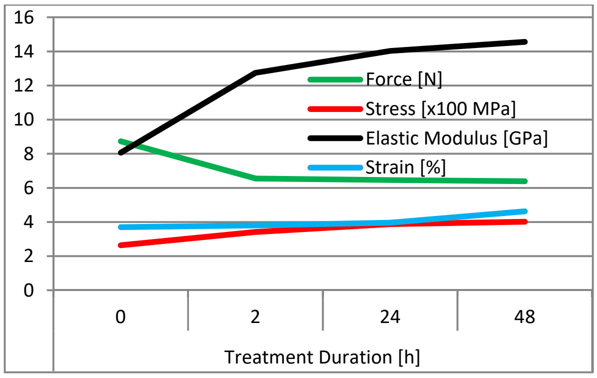

Fig. 15 Effect of treatment duration on rupture force, strain, stress, and elastic modulus

As shown in Fig. 15, if the effects of other factors assumed insignificant, treatment duration can affect rupture force, strain, stress and elastic modulus of Enset fiber. And, it was noticed here that as exposure duration of the fiber to treatment increases, rupture force is the only response that declines sharply until it becomes almost constant despite the treatment duration. This indicates that after the pectin component is dissolved totally, the cellulose is there to support the fiber whereas other responses such as stress, strain, and elastic modulus increase with treatment duration. There is observed phenomena where the stress is inversely proportional to force. This is due to the rate of decrease of force is by far less than the rate of decrease in the cross-sectional area of the fiber during the degradation of the fiber surface. Similarly, elastic modulus increases due to the rate of increase of stress is greater than the rate of increase of strain during the increased treatment duration.

IV. Conclusion

The result of this study came with promising data which proved that Enset fiber can be used for composite application as an alternative to the commercial fibers such as sisal, abaca, and banana. Enset fiber can not only be an alternative but it can be superior in specific strength to some natural fibers due to its low density.

The test result shows that a significant variation of rupture force does not mean that the rupture stress is also significant since the cross-sectional area of the fiber is the influencing factor. So, it is convincing to conclude that the higher the fiber diameter (raw fiber) the higher the rupture force, the lower the rupture stress.

The test result shows that the rupture stress variation is not significant among the fibers from 10 Enset breeds. However, strain variation is significant among the fibers from 10 Enset breeds. Breed Dego has the highest strain before failure. Surface treated fibers showed improved rupture strength and elastic modulus for 24 h treatment duration whereas the treatment duration less than and greater than 24h resulted in relatively poor values. Also, it was noted that both the rupture stress and strain increases in the top to bottom gradient whereas there is no significant variation across the stem. Elastic modulus variation both along and across the stem is insignificant. The rupture stress, elastic modulus and strain result of Enset fiber is 360.11 ± 181.86 Mpa, 12.80 ± 6.85 GPa and 0.04 ± 0.02 mm/mm, respectively. In addition, the insignificant variation of properties among breeds and across stem is good news for use of all breeds and all leaf sheath of the Enset fiber plant for fiber extraction. In this study, it is also noticed that the use of short natural fiber over the long is preferable to reduce the significant variation of properties along the stem or fiber direction.

As a whole, the results are crucial for Enset fiber composite design and development for specific applications. It can play great role in contributing to narrowing the knowledge gaps related to the properties of Enset fiber, in laying the foundation for further research on Enset fiber, in contributing to the improvement of the locally built lightweight materials, employment of the people in mass production of the Enset fiber with required form from its plant for commercial purpose which in turn brings economic development opportunities and increasing Enset plant plantation which brings food security to Ethiopia.

References

[1] A. Teklay, G. Gebeyehu, T. Getachew, T. Yaynshet and T.P. Sastry, 2017, Conversion of finished leather waste incorporated with plant fibers into value added consumer products – An effort to minimize solid waste in Ethiopia, Waste Management V68 Page 45–55.

[2] A. S. Singha and Raj K. Rana, 2012, Natural fiber reinforced polystyrene composites: Effect of fiber loading, fiber dimensions and surface modification on mechanical properties, Materials and Design Vol.41 Page 289–297.

[3] Admasu Tsegaye and P.C. Struik, 2000, Influence of repetitive transplanting and leaf pruning on dry matter and food production of Enset (EnsetWelw. (Cheesman)), Field Crops Research V68 Page 61–74.

[4] Ashenafi Chaka Tuffa, Tadesse Kenea Amentae, Tesfaye Balemi and Girma Gebresenbet, 2017, Assessment of post-harvest losses of Warqe food products along the supply chain in Central Ethiopia, African Journal of Agricultural Res, Vol. 12(9), pp. 750-763.

[5] ASTM D3379- Strength and Young's Modulus for High Modulus Single Filament Fibers," ASTM Standards, 1975.

[6] Athijayamani, A., 2009, Studies on the Mechanical Properties and Machinability of Roselle-polyester and Roselle/sisal-polyester Hybrid Composites. Ph.D. Thesis. Anna University, Chennai, India, http://hdl.handle.net/10603/34346.

[7] Beakou, A., Ntenga, R., Lepetit, J., Ateba, J.A., Ayina, L.O., 2008. Physico-chemical and microstructural characterization of "*Rhectophyllum camerunense*" plant fiber. Compos. Part A: Appl. Sci. Manuf. 39(1), 67-74.

[8] Bos HL, Van den Oever MJA, Peters O., 2002, Tensile and compressive properties of flax fibers for natural fibre reinforced composites. J Mater Sci; 37 (8):1683–92.

[9] C. Elanchezhian, B. Vijaya Ramnath, G. Ramakrishnan, M. Rajendrakumar, V. Naveenkumar and M.K. Saravanakumar, 2018, Review on mechanical properties of natural fiber composites, Volume 5, Issue 1, Part 1, Pages 1785-1790.

[10] Č. Mizera, D. Herák, P. Hrabě, M. Müller, A. Kabutey, 2016b, Effect of Length of False Banana Fibre (*Ensete ventricosum*) on Mechanical Behaviour unde rTensile Loading, Scientia agriculturae bohemica, 47, :90–96.

[11] Č. Mizera, M. Muller, D. Herak and P. Hrabě, 2015, Mechanical behaviour of polymeric composite with fibers of false banana (*Ensete ventricosum*), Agronomy Research 13(3), 680–689.

[12] C. Mizera, David Herak,PetrHrabe, Miroslav Muller, and Abraham Kabutey, 2016a, Mechanical Behavior of Enset Fiber Under Tension Loading, Journal of Natural Fibers, ISSN: 1544-0478.

[13] C. Mizera, Petr Hrabe, David Herak, and Abraham Kabutey, 2017, Effect of temperature and moisture contenton tensile behaviour of false banana fibre (*Ensete ventricosum*),Int.Agrophys., V31, Page 377-382.

[14] Cosgrove, D. J., 2005, Growth of the plant cell wall. Nature Reviews Molecular Cell Biology, 6(11), 850–861.

[15] CSA, 2011, Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season), the Federal Democratic Republic of Ethiopia, Vol. I

[16] Faruk, O., Bledzki, A.K., Fink, H.-P., Sain, M., 2012, Biocomposites reinforced with natural fibers: 2000e2010. Progr. Polymer Sci. 37, 1552e1596

[17] Govardhangoud and RN Rao, 2011, Effect of fiber content and alkali treatment on mechanical properties of Roystonearegia-reinforced epoxy partially biodegradable composites, Indian Academy of Sciences, Bull. Mater. Sci., 34, No.7

[18] H. Dahy, 2017, Biocomposite materials based on annual natural fibers and biopolymers – Design, fabrication and customized applications in architecture, Construction and Building Materials, Vol.147, Page 212–220

[19] https://www.openstreetmap.org, Retrieved by March 15, 2019)

[20] Inderdeep Singh and Pramendra Kumar Bajpai, 2012, Natural Fiber Reinforced Bio-Composites: Opportunities and Challenges, In Abstracts, Indo-Danish Workshop on Future Composites Technologies for Wind Turbine Blades, pp. 9-10.

[21] Jacob, M., Varghese, K.T. and Thomas, S. (2004a)Natural rubber composites reinforced with sisal/oil palm hybrid fibers: tensile and cure characteristics. J. Appl. Polym. Sci., 93, 2305–2312.

[22] JorgMüssig, Holger Fischer, *Nina Graupner* and Axel Drieling, 2010, Testing Methods for Measuring Physical and Mechanical Fibre Properties (Plant and Animal Fibers), In: Müssig J. (Ed.), Industrial Applications of Natural Fibers Structure, Properties and Technical Applications. John Wiley & Sons, Chichester, pp. 269–3095

[23] K. Alagarraja, A. Dhamodharan, K. Gopinathan, R. Mathan Raj and K. Ram Kumar, 2014, Fabrication and Testing of Fibre Reinforced Polymer Composites Material, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e- ISSN: 2278-1684, p-ISSN : 2320–334X PP 27-34.

[24] Kazmierski, C of Lucintel, 2012, Growth opportunities in global composites industry, 2012-2017, composites 2012, the composites exhibition and convection, February 21-23, 2012, Mandalay bay Convection Center, Las Vegas, NV, http://www.lucintel.com/lucintel-globalcompositemarketanalysis.

[25] L.A. Pothan, S. Thomas and N.R. Neelakantan, 1997, Short banana fiber reinforced polyester composites: mechanical, failure and aging characteristics, J. Reinf. Plast.Comp. Vol. 16, Page 744–765.
[26] M. Truong, W. Zhong, S. Boyko & M. Alcock (2009) A comparative study on natural fibre density measurement, The Journal of The Textile Institute, 100:6, 525-529, DOI: 10.1080/00405000801997595.
[27] M. Zaleha, S. Mahzan and I. Maizlinda Izwana, 2012, A Review on the Mechanical and Physical Properties of Natural Fiber Composites, Applied Mechanics and Materials Vols. 229-231, pp 276-281.
[28] Mangesh D. Teli and Jelalu M. Terega, 2017, Chemical, Physical and Thermal Characterization of *Ensete ventricosum* Plant Fibre, International Research Journal of Engineering and Technology (IRJET), Volume: 04 (12), p-ISSN: 2395-0072.
[29] Mohammed B., Martin Gabel and Laila M. Karlsson, 2013, Nutritive values of the drought tolerant food and fodder crop Enset, African Journal of Agricultural Research, Vol. 20(8), pp. 2326-2333.
[30] N. Olaru, Lilianaolaru, GH. Cobiliac, 2004, Plasma-Modified Wood Fibers as Fillers in Polymeric Materials, 5th International Balkan Workshop on Applied Physics, Vol. 50.
[31] Nurfeta, A., L. O. Eik, A. Tolera, and F. Sundstolf, 2008, Chemical composition and in sacco dry matter degradability of different morphological fractions of 10 Enset (*Ensete ventricosum*) varieties, Animal Feed Science and Technology 146:55–73. doi:10.1016/j.anifeedsci.2007.12.003.
[32] Höfte, H., Peaucelle, A., & Braybrook, S., 2012, Cell wall mechanics and growth control in plants: The role of pectins revisited. Frontiers in Plant Science, 3(121).
[33] Pickering, K.L., Beckermann, G.W., Alam, S.N., Foreman, N.J., 2007, Optimising industrial hemp fibre for composites. Compos. A Appl. Sci. Manuf. 38, 461e468.
[34] Prasanna Kumar Ilankeeran, Preetamkumar M. Mohite and Sudhir Ka, 2012, Axial Tensile Testing of Single Fibers, Modern Mechanical Engineering, Vol.2, Page 151-156.
[35] Phyo P, Tuo Wang, Sarah N. Kiemle, Hugh O'Neill, Sai Venkatesh Pingali, Mei Hong, and Daniel J. Cosgroveb, 2017, Gradients in Wall Mechanics and Polysaccharides along Growing Inflorescence Stems1 (OPEN), Plant Physiology, Vol. 175, pp. 1593–1607, www.plantphysiol.org2017 American Society of Plant Biologists. All Rights Reserved.
[36] Ramadevi Punyamurthy, Dhanalakshmi Sampath kumar, Raghu Patel Gowda, Ranganagowda Basavaraju Bennehalli, Pramod Vasudev Badyankal and Srinivasa Chikkol Venkateshappa, 2014, Tensile Properties of Abaca Fiber Reinforced Polypropylene Composites, International Journal of Chemistry, ISSN:2051-2732, Vol.35, Issue.2.
[37] Rongpipi S, Ye D, Gomez ED and Gomez EW (2019) Progress and Opportunities in the Characterization of Cellulose – An Important Regulator of Cell Wall Growth and Mechanics. *Front. Plant Sci.* 9:1894. doi: 10.3389/fpls.2018.01894.
[38] Rudi Dungani, Myrtha Karina, Subyakto, A. Sulaeman, DedeHermawan and A. Hadiyane, 2016, Agricultural Waste Fibers Towards Sustainability and Advanced Utilization: A Review, Asian J. Plant Sci., 15 (1-2): 42-55.
[39] S.V Joshi, L.T Drzal, A.K Mohanty, S. Arora, 2004, Are natural fiber composites environmentally superior to glass fiber reinforced composites?, Composites Part A Volume 35, Page 371–376.
[40] S.V. Prasad, C. Pavithran and P.K. Rohatgi, 1983, Alkali treatment of coir fibers for coir-polyester composites, Journal of Materials Science V18 page 1443-1454.
[41] Saira Taj, Munawar Ali Munawar and Shafiullah Khan, 2007, Review Natural Fiber-Reinforced Polymer Composites, Proc. Pakistan Acad. Sci. Vol. 44 Page: 129-ASTM Standards: Designation: D 638 – 03, Standard Test Method for Tensile Properties of Plastics, Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.
[42] Suhelmidawati, Etri, 2016, Tensile Tests of Abaca Fiber as One of Alternative Materials for Retrofitting of Unreinforced Masonry (URM) Houses, *Rekayasa Sipil Volume XIII No 2, Oktober 2016 ISSN : 1858-3695*22.
[43] Sasa Sofyan Munawar, Kenji Umemura, Shuichi Kawai, 2007, Characterization of the morphological, physical, and mechanical properties of seven nonwood plant fiber bundles, J Wood Sci (2007) 53:108–113 © The Japan Wood Research Society 2006 DOI 10.1007/s10086-006-0836-x.
[44] Ticolau, A., Aravinthan, T, Cardona, F.: A, 2010, review of current development in natural fiber composites for structural and infrastructure applications. Toowoomba: University of Southern Queensland, 5 p. SREC2010- F1-5.
[45] Tsegaye, A., 2002. On indigenous production, genetic diversity and crop ecology of Enset (*Ensete ventricosum*) (Welw.) Cheesman. Ph.D. Thesis. Wageningen University.
[46] Yemataw Z, 2010, Variability study and indigenous classification method of Enset (*Ensete ventricosum* (Welw.) Cheesman) clones in southern Ethiopia. MSc., Thesis, Hawassa University, Hawassa, Ethiopia.
[47] Yemataw Z., H. Mohamed, M. Diro, T. Addis, and G. Blomme, 2014, Enset (*Ensete ventricosum*) clone selection by farmers and their cultural practices in Southern Ethiopia, Genetic Resources and Crop Evolution Vol. 61 Page 1091–1104.