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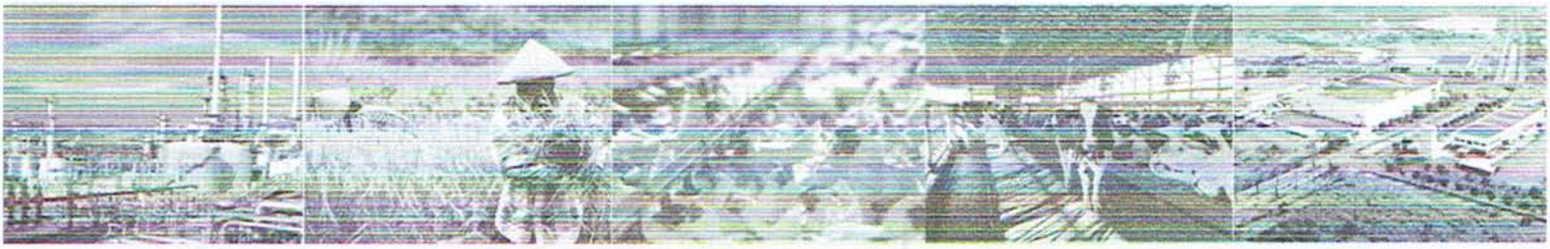

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Selecting Part of Natural Fiber EFB which has Best Mechanical Strength through Tensile Test Analysis for Composite Reinforced Material

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Abstract—**Natural fiber of EFB which is recently still categorized as waste material is very potential to be utilized as composite reinforced material, however it is remain constrained on resulting composite strength. Many treatment has been applying to obtain better mechanical bonding, however it was costly higher rather than its result and some did not increase the strength compare with matrix material strength itself. Previous researcher described that tensile strength of EFB was not as good as other natural fibers such as bamboo, sisal, pineapple leaf, and many others, furthermore it contains residual oil and several harmful minerals which had weakened its composite, therefore it is necessary for selecting part of natural fiber EFB which has best mechanical strength. This study explored morphology of an EFB, and separating it to 3 parts, ie: upper stem, main stem, and fruit stem. Those 3 parts was examined and base on tensile strength analysis, the leaf stem has best mechanical strength, and it also shown more stiff structure compare with 2 others. Tensile strength analysis result using ASTM D3822-01 standard shown that average tensile strength of an EFB leaf stem single fiber was 152,85 MPa, while upper stem fiber and main stem fiber was 108,29 MPa and 125,13 respectively.**

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I. INTRODUCTION

Indonesia is a world biggest crude palm oil (CPO) producer with a total land growth of 7.6% during 2004-2014 [6] and projected to produce 40 million tons in 2020[4]. Currently on 10.9 million hectares of land, 29.3 million tons of CPO [6] is produced by 608 units of palm oil mill spread unevenly across the major islands in Indonesia [4], and it is concentrated on the island of Sumatra, especially in Riau Province.

Oil palm empty fruit bunches (EFB) which is 21% -24% share part of the total fresh fruit bunches (FFB) has not been utilized optimally. Palm oil mill generally returns EFB into plantations to be used as fertilizer. However, because of the large numbers, and transportation costs are expensive, and not comparable with the needs of the fertilizer itself, then finally palm oil mill granted to accumulate this EFB in open fields, and this deposit potentially produces methane gas released into open air causing damage to the ozone layer.

EFB is a fibrous material that is hard and tough and it shows morphological similarities with coconut coir [26]. SEM (scanning electron microscopic) image of fiber TKKS taken from a transverse position can be seen in Figure 5 which shows the presence of lacuna like portion in the middle surrounded by a porous tubular structure [26]. The pores of fibre surface has 0.07 μm average diameter and this porous surface is useful to produce a better mechanical interlocking with the epoxy matrix material in the composite fabrication [26]. However the porous surface structure also facilitates the penetration of water into the fiber by capillary action, especially when it is exposed to water [13].

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Fig. 1 Accumulated EFB that is waiting to be returned to the field (Source: PTPN 13)

Starch granules found in the interior of vascular bundles of EFB [16]. Silica bodies are also found in great number on fiber strand. They attach themselves to circular craters which are spread uniformly over the fiber surface. The silica bodies, through hard, can be dislodged mechanically, leaving behind perforated silica-crater, which would enhance penetration of matrix in composite fabrication [24]. High cellulose content [25] and high toughness value [9] of EFB make it suitable for composite applications. However presence of hydroxyl group makes the fibers hydrophilic, causing poor interfacial adhesion with hydrophobic polymer matrices during composite fabrication. This may lead to poor physical and mechanical properties of the composite [19]. EFB fiber also contain oil residue around 4.5% [1] that will significantly influence the fiber-matrix compatibility.

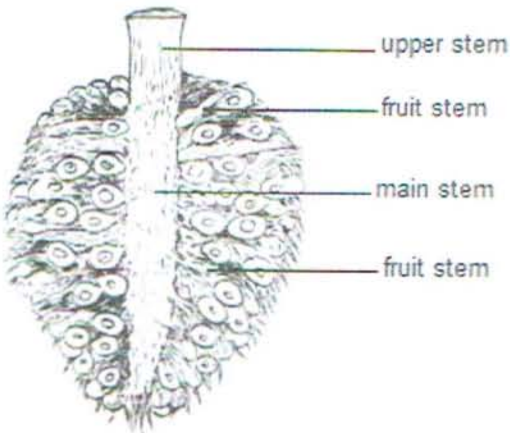

Fig. 2 EFB fiber morphology which classifies fiber according to body composition and function

The ester components of which may affect coupling efficiency between fiber and polymer matrix as well as the interaction between fiber and coupling agents [20].The fiber properties can be improved substantially through surface modifications. Chemical treatments decrease hydrophilic property of the fibers and also significantly increase wettability with polymer matrix [11]. There are number of treatment methods on EFB to improve its properties and make it compatible with polymeric matrices. Shinoj et al (2011) have studied EFB fiber and conclude that it is suitable for composite raw material. EFB containing cellulose in the range of 43% - 65% and Lignin of 13% - 25% make it compatible with several polymer raw materials such as natural rubber, polypropylene, polyninyl chloride, phenol formaldehyde, polyurethane, epoxy, and polyester.

There are several treatments to improve the properties of EFB fiber to make it suitable and coupled with its polymer matrix. Compatibility can be improved by providing an alkali treatment on natural fiber. Alkali treatment is immersing natural fiber into a 5% solution of sodium hydroxide that will increase the flexural modulus of composite materials [23]. The solution eliminates the hemicelluloses and lignin from kenaf fiber surface so that compatibility for the better. Alkali treatment on fiber flax above 10% sodium hydroxide lowers the composite tensile stress. This is caused by changes in the chemical structure of owned fiber wherein the cellulose molecule chains lose local crystalline structure due to alkali treatment [5].

It is more convenient to model the composite on a macro scale continuum level. An analogy is to model steel as a homogenous material instead of modeling the crystals and grains. The method used when determining the macro scale continuum properties from the micro scale properties, is referred to as homogenization. The macro scale properties are obtained by analyzing a representative volume element, RVE, of the composite on a micro scale. The macroscopic properties of a composite, i.e: its density, stiffness, thermal and hygro expansion etc are determined by the equivalent properties of the fibre and matrix materials. A central parameter in micro mechanical modeling is the volume fraction of the fibers and the matrix. The volume fractions are Vf and V_m for the fibre and the matrix respectively. Vf and V_m are defined such that:

$$Vf + V_m = 1 \qquad (1)$$

This relation is valid if the composite is solid, i.e. it does not contain any pores.

By assuming that the strain in a RVE is homogeneous, the stiffness of a composite can be approximated by [7]:

$$\mathbf{D}c = Vf\mathbf{D}f + Vm\mathbf{D}m \qquad (2)$$

where $\mathbf{D}_c$, $\mathbf{D}_f$ and $\mathbf{D}_m$ are the stiffness matrices of the composite, fiber and the matrix respectively. V_f is the volume fraction of the fibers and V_m the volume fraction of the matrix. Equation 2 is referred to as the Voigt approximation, the rule of mixture (ROM) or the parallel-coupling model. The

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approximation might be more familiar in its one-dimensional form:

$$Ec = VfEf + VmEm \quad (3)$$

where E_c, E_f and E_m are the E-modulus of the composite, the fibre and the matrix respectively.

If the stress field is assumed to be homogeneous, the compliance matrix can be approximated according to [7]:

$$\mathbf{C}c = Vf\mathbf{C}f + Vm\mathbf{C}m \quad (4)$$

and its one-dimensional form:

$$\frac{1}{Ec} = \frac{Vf}{Ef} + \frac{Vm}{Em} \quad (5)$$

which is referred to as the Reuss approximation or the series-coupling model.

It should be mentioned that both the Voigt and Reuss approximations are incorrect on the micro scale level. Assuming a uniform strain field of the RVE leads to that the tractions at the boundaries of the phases cannot be in equilibrium. Similarly, if the stress field is assumed to be uniform, the matrix and the reinforcement material cannot remain bonded.

Refer on above explanation, it is known that the strength of composite materials in receiving mechanical loads can be improved by using fiber reinforcing material which has high mechanical strength and stiffness, and also improves wettability to increase interfacial bonding between resin-fiber. Therefore used EFB fiber raw materials must have as high strength and uniformity as possible, since the out coming strength of composite is significantly determined by it. In addition, the fiber treatment process is proposing to improve wettability, and not to weaken the strength of the fiber itself, accordingly it needs to be controlled to obtain optimal conditions.

So far, some recent literatures that have been reviewed showed that previous research has not been sorting EFB fiber in part by part, but in integral part. It is predicted in because of preparation process in separating it into parts is quite hard to do, and many researchers obtain the raw EFB material fiber instantly from preparation machinery that has been processed by large-scale factory, and it is without any prior sorting process. This could be resulting strands of fiber with high variance strength level. Based on this study, the goal of this research is founding the part of EFB fiber which has best mechanical strength through tensile test analysis for composite reinforce material by selecting it each part by part as illustrated on Figure 2.

2. METHOD

Sampling of palm oil EFB conducted in PTPN VIII Business Unit 1 owned palm oil mills (PKS) at Cikasungka Plantation – Bogor Regency. EFB sorting was separation process between the main stem and fruit stem by slicing method using conventional blade. Fiber preparation process was done mechanically to get single fiber, while eliminating water, oil, and dirt clinging to each part of the EFB.

Fig. 3 EFB sorting process by separating between the main stem and fruit stem

Instead of main stem and fruit stem, the other EFB part that will be analyzed is upper stem which have biggest diameter. Based on the early hypothesis, upper stem which is closest to the palm oil tree sustains the heaviest load of fresh fruit bunch (FFB); therefore testing will be focused to the upper stem of FFB which is closest to the tree. Based on the above hypothesis anyway, it also conducted sampling of the upper stem that is left at land. When harvesting, most of farmer generally cuts perfectly near to a FFB (≤ 5 cm) to lower down the size and weight [2], and left upper stem on the tree or cut it before transport and left it on land. Thus it is possible for upper stems are left on land has the best mechanical strength since it pays the load of FFB which some can have weight up to 50 kg.

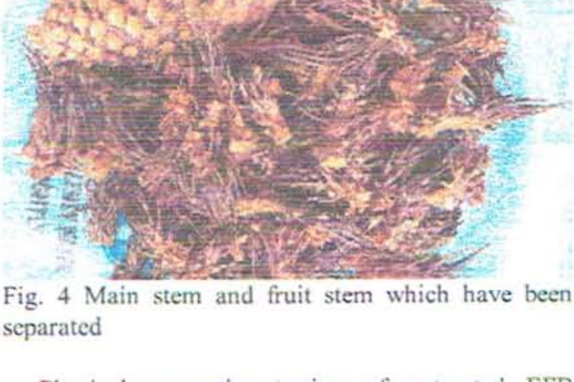

Fig. 4 Main stem and fruit stem which have been separated

Physical properties testing of untreated EFB carried out in the laboratory of Bio Material LIPI -

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Cibinong. EFB single fiber diameter is measured by Optical Microscope Zeiss Axio Imager type with 50 times magnification. Three types of fiber samples (BA;upper stem, BU;main stem, and BB;fruit stem) water content were measured with a dry basis, and then those samples are taken randomly each 50 pieces to be measured. This measurement is intended to generate value of cross sectional area A, and then the tensile strength values can be formulated as follow:

$$\sigma UT = \frac{F}{A} \qquad (5)$$

σ_{UT} = Ultimate tensile strength
F = Peak force when fiber broken off while tensile test in Newton
A = Cross-sectional area in mm^2

Figure 5 ~ 7 are fiber strand illustrations of each part of EFB. Each fiber section is coded as BU (main stem), BB (fruit stem), and BA (upper stem). Photos are taken by using a microscope with a magnification of 50 times.

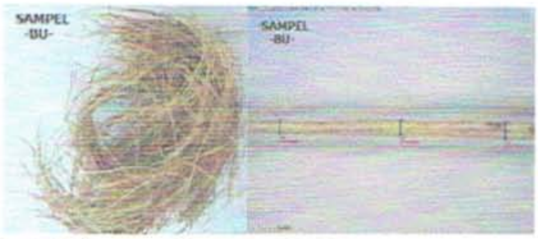

Fig. 5 Main stem fiber strand (BU)

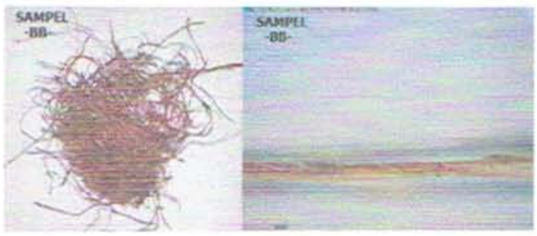

Fig. 6 Fruit stem fiber strand (BB)

Fig. 7 Upper stem fiber strand (BA)

2.1. Specimen Making

Tested specimens were made by using ASTM 3822-01 standard. Fibers were dried to achieve moisture content <40%. Specimens were prepared are 50 pieces of each fiber parts, bringing the total to 150 specimens. Figure 8 below shows how the fiber is prepared before the tensile test.

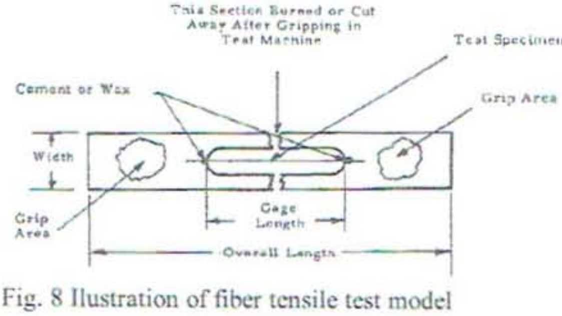

Fig. 8 Ilustration of fiber tensile test model

Every single piece of fiber specimen takes two sheets of 200 grams cardboard and was formed using a paper cutter. Fiber then attached using epoxy glue to provide a good grip. Figure 9 illustrates some of the specimens that have been made.

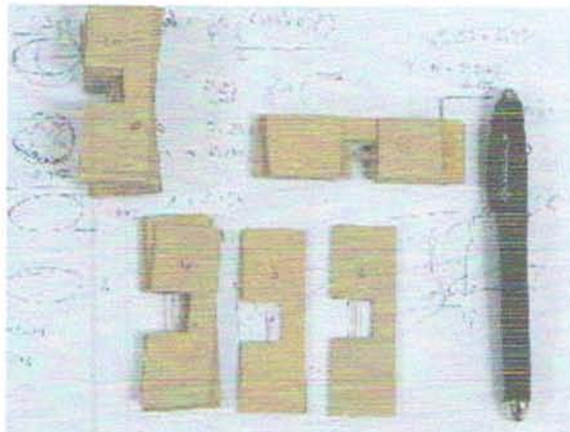

Fig. 9 Fiber strands that were ready to be tested

Specimens were left for ± 24 hours for perfectly glue curing to prevent fiber slippage during testing and fibers pull out. Fiber slippage may affect on test results, especially related to modulus of elasticity value.

2.2. Testing Procedure

Tensile test procedures were firstly attached the load cell in UTM (universal testing machine) with a maximum load 1kN, then the specimen was placed on the center of vise jaw, and then locked to prevent shifted from its original position. In order to left single fiber only, we cut Paper on specimens with scissors. To provide real fiber strength data, we need to enter the diameter value of the fiber under test into UTM software, and then press the start button to begin tensile testing process. When the fibers began to be pulled, the graph on the screen will start to be seen, showing that the fiber tensile stress began to be detected.

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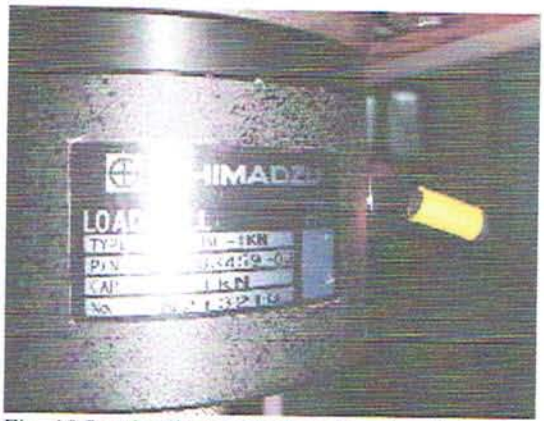

Fig. 10 Load cell were used on fiber tensile testing

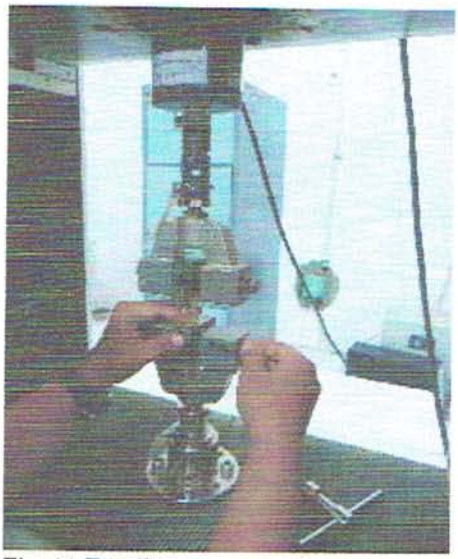
Fig. 11 Tensile test preparation process

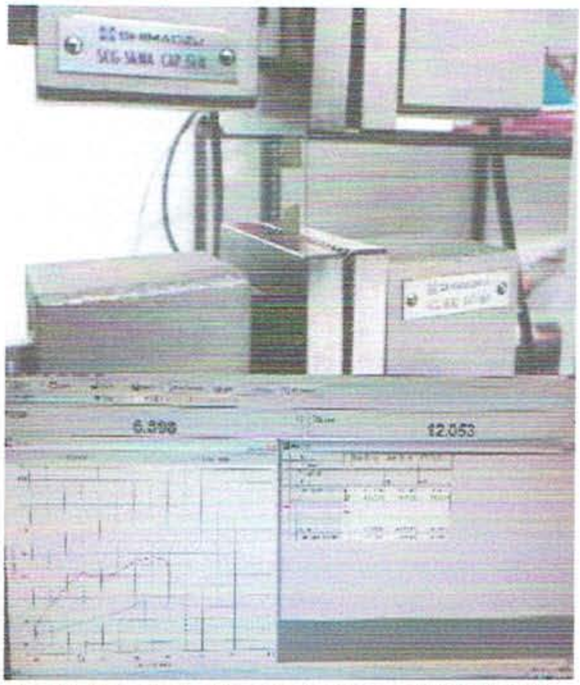

Fig. 12 Tensile loading mechanism and tensile test graphs

3. RESULTS AND DISCUSSION

Post boiled EFB which had been threshed has moisture content of approximately 67% [28], so in order to complete the mechanical properties test data, test specimens also conducted testing of the physical properties. It was expected to get as much as possible the fiber under test to represent the current state of the fiber that will be fabricated as composite materials. One of the three fiber specimen which was measured its density, fruit stem (BB) density was the lowest, and showed uniqueness.

TABLE I
PSYSICAL PROPERTIES OF EFB FIBER

No.	SAMPLE	MOISTURE CONTENT (%)	DENSITY (g/cm^3)
1.	Main stem	19.03 +3.68	1.07+0.04
2.	Upper stem	19.01 ±7.35	1.03+0.03
3.	Fruit stem	16.00.+ 4.14	1.02+0.03

Chemical properties of EFB samples were also tested as a reference, but in generally the results are almost similar with previous research. However, there are again a uniqueness shown by fruit stem EFB fibers (BB), which showed lowest lignin content than other parts of EFB fiber, which is 13.53%. This indicates that the fruit stem fibers expect to be easier in pre-treatment process to remove lignin content due to lesser content of lignin, and this is a value added when it is used as composite materials.

TABLE II
CHEMICAL PROPERTIES OF EFB FIBER

NO	T EST	Fruit Stem		Upper Stem		Main Stem		Standard Method
		RESULT (%) Dry Base	Standar Dev	RESULT (%) Dry Base	Standar Dev	RESULT (%) Dry Base	Standar Dev	
1	Water Content	10,91	0,099	5,983	0,064	7,173	0,037	TAPPI TM T412 OM94
2	Ethanol-Benzene Extractive content	2,696	0,007	3,007	0,035	2,956	0,014	TAPPI TM T204 OS76
3	Klason Lignin	13,53	0,047	19,8	0,231	17,26	0,248	TAPPI TM T222 0M88
4	Holo-Cellulose	49,5	0,385	62,07	0,465	60,15	0,145	TAPPI TM T203 OM93
5	α-Cellulose	30,28	0,669	38,22	0,408	36,14	0,107	TAPPI TM T429 CM01
6	Hemicellulose	19,49	0,669	23,52	0,408	24,11	0,107	By difference

The next discussion will be tensile test result that will test 50 samples per each part. It will be drawn at random a number of 15 pieces which still meet the population standard samples are permitted. This was because in each 50 pieces of samples per part, there

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were several damaged, and ignored. The damage was mainly caused by imperfectly gluing process and caused slippage when fibers were pulled. The error indicated by ambiguous graph which was showed abnormal condition on fiber material.

The main stem EFB fiber (BU) showed unfavorable results, although these fibers are the longest part of EFB fibers. Furthermore tensile graphic presentation of test results are presented in Figure 13,14, and 15.

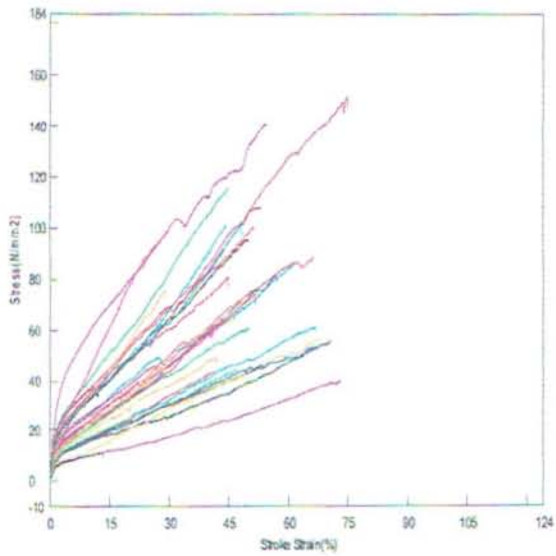

Fig. 13 Stress-strain graph for testing main stem fiber (BU) with 50 population

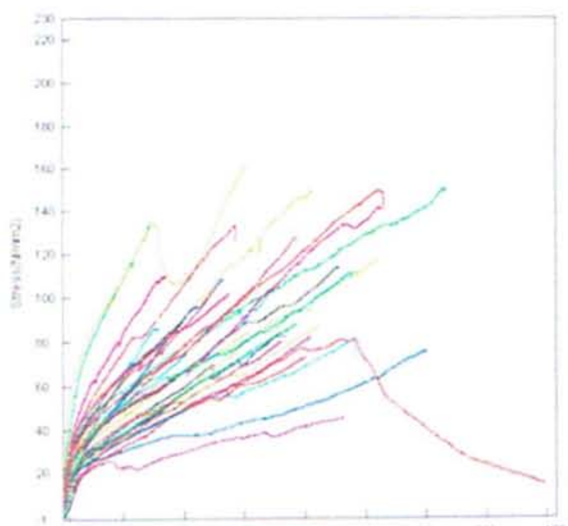

Fig. 14 Stress-strain graph for testing upper stem fiber (BA) with 50 population

Visual observation showed some samples had abnormal tensile test graph (Figure 14). This indicated the possibility of slippage on the fiber during testing. These cases are common in natural fibers that cause high standard deviation if abnormal sample result is calculated and put into the statistical calculations. In case of natural fibers, the stress-strain graph obtained is very random so difficult to determine the value of the modulus of elasticity that truly reflect the characteristics of the material. Elongation (ε) obtained is not worth the constant and very varied and changed very diverse. As for displayed value (stress, strain, and modulus of elasticity) derived from software processed UTM (Universal Testing Machine).

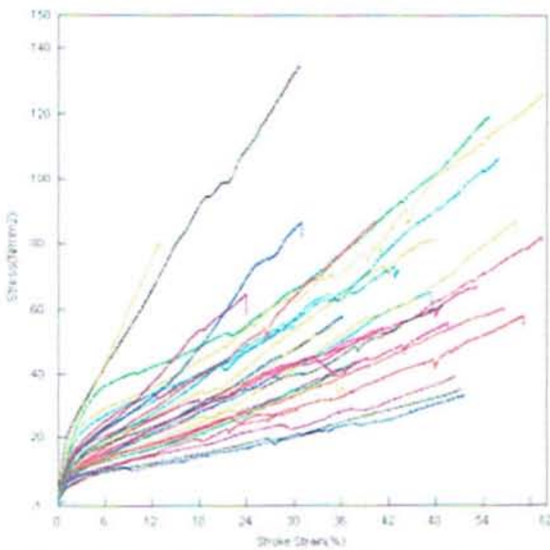

Fig. 15 Stress-strain graph for testing fruit stem fiber (BB) with 50 population

All of tensile test results generated by UTM using Shimadzu AG-IS 1 kN, with software Trapezium 2; 2003, which was operator's role was limited to input testing the sample data include: the dimensions (width, length, thickness, diameter, etc.), number and shape, the type of testing (tensile, pressure, bending, shear), and data output (tensile strength, modulus of elasticity, strain, force, displacement, and charts). If raw data is needed, the output data will be only force, displacement and time with 0.05 seconds of interval. As for tensile strength, elongation, and modulus of elasticity output, it is needed to entered data of dimensions and tensile strength equation (Force / A (area)). Whereas elongation and modulus elasticity result data was determined by the machine.

It is commonly understood that the tensile strength of the material has a transition pattern, which are elastic area, semi-plastic and plastic that is clear and mapped. Then (σ) = Eε, and understood the value of the modulus of elasticity (E) is proportional to the tensile strength (σ) with the assumption that the value of ε is constant. In this case, it appears a postulate that if tensile strength is high, then modulus of elasticity is also high, and vise versa. This is actually cannot be generalize in all type of materials, but as for the fiber almost commonly accepted.

TABLE III
MECHANICAL PROPERTIES OF EFB FIBER

No.	SAMPLE	TENSILE STRENGTH (MPa)
1.	Main stem	125.13
2.	Upper stem	108.29
3.	Fruit stem	152.85

Table 3 informs the average yield statistics on tensile test data. These results indicate that the fruit stem fiber has highest tensile strength. This is also break the early hypothesis that the upper stem EFB fiber has highest strength due it sustains fresh fruit bunches that can weigh up to 50 kg. Furthermore, even the main stem has longest fiber, it turns tensile strength is not as good as the fruit stem.

This is a positive result due in chemical testing showed that the lignin content in fruit stem fiber turns the lowest compared to other parts EFB fiber. It is certainly easier for us to do a lignin removal treatment process to improve the compatibility of EFB fruit stem fiber with matrix material, particularly of polymeric material.

In the mean time the results of physical properties testing are also quite positive, because the density of the fruit stem of EFB fiber turns lowest. It is encouraging composite maker since produced material will be lighter.

4. CONCLUSIONS

Fruit stem fiber is a part of the palm oil EFB fiber which has highest tensile strength and the best compared with two others ie; main stem and upper stem. It is also a part of the EFB fiber which has a lowest lignin content compared with two others. In addition, this fiber also has lowest density. Based on initial analysis, it was concluded that fruit stem EFB fiber was part of the EFB which is most suitable for being used as a reinforcing material for FRP composite material with a polymeric matrix.

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