Jurnal Teknologi

Full Paper

MECHANICAL PROPERTIES AND SURFACE FREE ENERGY OF OIL PALM EMPTY FRUIT BUNCHES FIBRE REINFORCED BIOCOMPOSITES AS GLASS FIBRE SUBSTITUTION

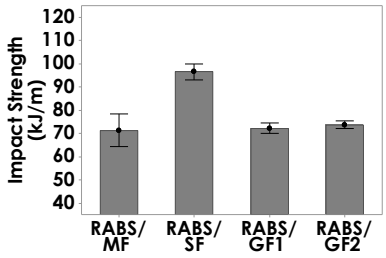
Gema Sukmawati Suryadi[a], Siti Nikmatin[b*], Sudaryanto[c], Irmansyah[b]

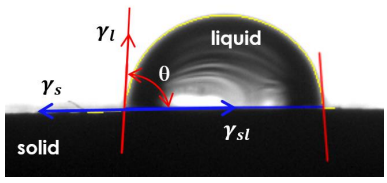
[a]Biophysics, School of Graduate Studies, Bogor Agricultural University, 16680 Bogor, Indonesia
[b]Department of Physics, Faculty of Mathematics and natural Science, Bogor Agricultural University, 16680 Bogor, Indonesia
[c]Center for Science and Advanced Materials Technology, National Nuclear Energy Agency of Indonesia, South Tangerang, Indonesia

Article history
Received
21 December 2016
Received in revised form
17 March 2017
Accepted
30 March 2017

*Corresponding author
snikmatin@apps.ipb.ac.id

Graphical abstract





Abstract

Study of the size effect of natural fibre from oil palm empty fruit bunches (OPEFB) as filler, onto the mechanical and physical properties of fibre reinforced biocomposites based on recycled Acrylonitrile Butadiene Styrene (ABS) has been done. The OPEFB fibres were prepared by mechanical milling and sieving to obtain medium-fiber (20 mesh) and short-fiber (100 mesh). The biocomposites have been produced by extrusion using single-screw extruder method. Mechanical properties and S of biocomposites were evaluated and compared with glass fibre (GF) filled composite which is commonly used in plastics industrial applications. The result showed that the impact strength increased with the decreasing of OPEFB fibre size, while the Young's modulus decreased. Other mechanical properties of biocomposites with short-fibre (RABS/SF) and medium-fibre (RABS/MF) filler were not significantly different at 95% confidence interval. Impact strength of short-fibre filled biocomposite was higher than glass fibre filled composites. The surface free energy of biocomposites lower than glass fibre filled composites, but its dispersive components are higher, indicating more hydrophobic feature of the surface. The fabricated micro-fibre of OPEFB can be used as viable alternative to substitute glass fibre as filler materials of composites.

Keywords: Biocomposites, empty fruit bunches, recycled ABS, impact strength, surface free energy

1.0 INTRODUCTION

Indonesia and Malaysia hold the domination over global oil palm production. Both countries produce around 85-90% of the total oil palm production. Currently, Indonesia is the largest oil palm producer and exporter across the globe. Total area and productions of oil palm in Indonesia in 2015 was 11,444,808 hectares and 30,948,931 tons [1]. Therefore, the oil palm empty fruit bunches waste was quite large with an annual yield of 6 million tons (recorded in 2004), 23% per ton of fresh fruit bunches (FFB) [2]. Oil palm empty fruit bunches (OPEFB) is the fibrous mass left behind after separating the fruits from sterilised (steam treatment) FFB. Among the various fibre sources in an oil palm tree, OPEFB has

potential to yield up to 73% fibres [3]. OPEFB fibre is tremendously abundant, renewable, and can be converted into value-added products, such as filler material for composites.

Natural fibres have been used as reinforcement in polymer composites during the last decades. OPEFB as one of natural fibre biomass offer some advantages when considered for composites applications. They are available in large amounts, low cost, low density, renewable and biodegradable. On the other hand, thermoplastic materials, like Acrylonitrile butadiene styrene (ABS) has been consumed intensively to fulfill increasing demands of cheap materials in modern civilisation. ABS is an important engineering copolymer widely used in industry due to its superior mechanical properties, chemical resistance, ease of processing and recyclability [4]. As a common component in consumer electronic housing, automobiles and motorcycles, ABS has wide application and because of that there is a great need to develop materials using recycled ABS polymers [5]. Therefore, in this study, recycled ABS was used as a matrix polymer to compound with the OPEFB natural filler for the purpose of manufacturing the biocomposites. Broadly defined, biocomposites are composite materials made from natural fibre and petroleum derived from non-biodegradable polymers or biodegradable polymers [6], in other words, composites are termed as biocomposites materials when one of its phases either matrix (polymer) or filler (fibres) comes from natural sources [7].

In the early stage, carbon and glass fibre were commonly used as the reinforcement materials [8, 9]. Synthetic fibres have some advantages such as high strength, high modulus, light weight and easy installation [9]. Several recent studies about synthetic fibre reinforced composites for advanced applications have been intensified [10-13]. However, these materials are very expensive. On the other hand, bio-fibres have a renewable and biodegradable nature and low energy consumption during processing and also they are ecofriendly and cheaper than man-made fibres. The primary advantages of using OPEFB in composites are its low densities, greater deformability, less abrasiveness to equipment, renewable, high degree of flexibility, good acoustic and thermal insulation, less machine wear and good availability [9, 14-18].

Fibre content, length, and diameter can affect mechanical properties of polymer composites [19, 20]. The length to diameter ratio also called as aspect ratio of fibre has a significant effect on the properties of final composite materials. Aspect ratio in parallel with mechanical property of the OPEFB fibre can be improved by decreasing its diameter via physical, chemical, or thermal treatments [7]. Increase in filler size has reverse effect on the mechanical properties, except that for flexural toughness, which showed significant increase. The impact strength was found to decrease as the filler size was increased [21]. Yusoff *et al*. [22] explained that, about 67% decrease in aspect ratio caused a significant decrease in Young's modulus of OPEFB fibres.

Studies on the properties of surface materials, including surface free energy, are the subject of intensive scientific research for over forty years. These quantities are being assumed as important criteria for evaluation of adhesion properties of solid polymers [23]. Then the evaluation of surface free energy parameters was become a very useful tool for theoretical studies of the surface behaviour of biocomposites as well as for practical developments in many technological applications, such as painting, coating, or other surface treatments of materials. Thus, the effect of filler size on the surface free energy of biocomposites is important to be studied.

Based on these facts, in this study we investigated the effects of fibrr size of OPEFB fibrr as filler to the mechanical properties and surface free energy of biocomposites which are important to characterise the quality of the corresponding materials. We found that our fabricated reinforced biocomposites showed higher impact strength and dispersive components of surface free energy than glass fibre composites.

2.0 METHODOLOGY

2.1 Materials

The oil palm empty fruit bunches (OPEFB) was obtained from PTPN VIII Cikasungka, Bogor, West Java, Indonesia. The OPEFB were washed with water, drained under the sun over 2 days and then chopped into chips form about 2 cm^2. Chip samples then dried in a drying oven (Model YNC-OV, YENACO, China) at 100 °C for 8 hours. Fibers were prepared by mechanical milling (Model MDY-1000, FOMAC, China) then sieved to obtain medium-fibre (20 mesh) and short-fibre (100 mesh).

The recycled ABS (RABS) polymer (melt flow index 12.1 g/10 min) was purchased from PT MUB Jaya (Bogor, Indonesia). The additives used in this study are maleic anhydride (Darmstadt, Germany), primary antioxidant (Zaozhuang, China), and acid scavenger (Darmstadt, Germany). For the biocomposites comparison, commercially available E-glass composites was used in the current study. Two types of composites supplied by PT MUB Jaya (Bogor, Indonesia), imported glass fibre composites (Guangdong, China) as RABS/GF1 and local glass fibre composites (Bogor, Indonesia) as RABS/GF2. Both composite are ABS filled with 10% glass fibre.

2.2 Fiber Dimension and Oil Content Measurements

The average OPEFB fibre dimension was calculated from images captured by a light microscope (Model BX51, Olympus, Japan) with the software Olympus DP2-BSW integrated with DP25 Olympus Microscope Camera. The oil content of OPEFB fibre were measured using Soxhlet Apparatus with 3 gram samples and extraction for 6 hours using 150 ml of oil solvent (hexane).

2.3 Biocomposites Preparation

The biocomposites have been produced by extrusion using single-screw extruder (Model HXSJ-125/125, Kai Xin, China), blended with gradient temperature 195-215-220-220-220-225-225-225°C. Based on our previous research [20, 24] with variation of filler content viz. 10, 15, and 20%, the optimum filler composition was 15% (wt.) for short-fibre filled biocomposites. The composition of biocomposites is listed in Table 1. The obtained biocomposites in form of granular, were made into test piece (according to ASTM standard) by injection molding machine (Model HC-250, Hwa Chin, China) with gradient temperature 170-185-200°C.

Table 1 Composition of biocomposites

Designation	Composition				
	Filler	Matrix	MA	PO	AS
RABS/MF	15 % medium-fiber	81.7 % RABS	2 %	1 %	0.3 %
RABS/SF	15% short-fiber	81.7 % RABS	2 %	1 %	0.3 %

Note : RABS = Recycled ABS; MA = maleic anhydride; PO = primary antioxidant; AS = acid scavenger

2.4 Density Measurements

The density of OPEFB fibre was determined by using the liquid displacement method based on the Archimedes. It was carried out according to the standard (ASTM D 792-08) with distilled water and sensitive digital balance (Model PW-254, Adam Equipment, USA).

2.5 Measurements of Mechanical Properties

Tensile property was measured using Computer Control Electronic Universal Testing Machine (Model WDW-20, Jinan Hensgrand Instrument, China) according to ASTM D-638 at displacement speed of 50 mm/min. The gauge length was 50 mm which is the same as glass fibre filled composites (RABS/GF2 and RABS/GF1). The tensile strength, Young's modulus, and elongation at break were then evaluated.

The impact strength was carried out using the Izod Impact Testing Machine (Model XJU-22, Jinan Hensgrand Instrument, China) according to ASTM D-256A. All samples were notched before testing. Note that five samples were tested in each mechanical testing.

Mean values for mechanical properties were analysed statistically with analysis of variance (One-way ANOVA) using Minitab 17 Statistical Software. To determine statistically significant differences among the groups, the Fisher least significant difference (LSD) test was used after the *F*-test of the ANOVA was found to be significant at the 5% level.

2.6 Surface Free Energy Measurements

The surface free energy (SFE) of biocomposites were measured by the contact angle measurements using Phoenix 300 Contact Angle Analyser (Surface Electro Optics, Korea). Test liquids used in this study are described in Tables 2 and 3. Drops of 5 uL volume were employed and analysed for each liquid. The contact angle determinations were performed through the capture of the droplet images using Surfaceware 8 software and a camera based contact angle analysis system. All tests were carried out at room condition (temperature of 25 °C).

Table 2 SFE and their components (in mJ/m^2) for the probe liquids used for contact angle determination according to the Owen-Wendt method

Liquid	γ_l	γ_l^p	γ_l^d
Water	72.8	21.8	51
Hexane	18.4	18.4	0

Table 3 SFE and their components (in mJ/m^2) for the probe liquids used for contact angle determination according to the vOCG method

Liquid	γ_l	γ_l^{LW}	γ_l^{AB}	γ_l^+	γ_l^-
Water	72.8	21.8	51	25.5	25.5
Methanol	22.5	18.2	4.3	0.06	77
Hexane	18.4	18.4	0	0	0

The SFE and their components were calculated for all samples using Surfaceware 8 software, with three methods, Girifalco-Good-Fowkes-Young (GGFY) [25-27], Owens-Wendt [28, 29], and van Oss-Chaudhury-Good (vOCG) [30]. For GGFY, the liquid used was water (aquademineralised), with known total liquid SFE value 72.8 mJ/m^2. The probe liquid parameters used for the determination of the biocomposites surface energy are listed in tables 2 and 3, for Owen-Wendt and vOCG, respectively.

The basic methods of calculating SFE of a solid (γ_s) from measurements of the contact angle (θ) is due to Young equation [31]. It is given as:

$$\gamma_l \cos\theta = \gamma_s - \gamma_{sl} \quad (1)$$

where γ_l denotes SFE of liquid in contact with the solid and γ_{sl} means the interfacial free energy between the solid and the liquid. If the values of γ_l and θ are known, it is impossible to determine SFE directly from the equation (1) because of the two unknowns, γ_s and γ_{sl}. In order to solve this equation for γ_s, one has to add a second equation that correlates γ_{sl} with γ_s and γ_l. Until recently, many types of correlations have been employed. Girifalco-Good-Fowkes-Young (GGFY) method by equation (2):

$$\cos\theta = -1 + {2\left(\gamma_s^d \gamma_l^d\right)^{1/2}}/{\gamma_l} \quad (2)$$

Owens and Wendt method by equation (3):

$$(1+\cos\theta)\gamma_l = 2(\gamma_s^d\gamma_d^d)^{1/2} + 2(\gamma_s^p\gamma_d^p)^{1/2} \quad (3)$$

and van Oss, Chaudhuri, and Good (vOCG) method by equation (4):

$$(1+\cos\theta)\gamma_l = 2\left(\sqrt{\gamma_s^{LW}\gamma_l^{LW}} + \sqrt{\gamma_s^+\gamma_l^-} + \sqrt{\gamma_s^-\gamma_l^+}\right) \quad (4)$$

3.0 RESULTS AND DISCUSSION

3.1 Fiber Dimensions, oil content, and Density Values

The fibre dimensions and oil content of OPEFB medium-fibre and short-fibre are shown in Table 4. 10 fibres were selected randomly and measured for each medium-fibre and short-fibre. According to International Association of Wood Anatomy (IAWA) [32] fibre lengths classification, fibre length varies from short-fibres (≤900 µm), medium-fibre (900-1600 µm) and long-fibre (≥ 1600 µm). Therefore, EFB fibre length variations in this study were categorised into medium-fibre (average length of 1535.97 µm) and short-fibre (average length of 230.12 µm).

OPEFB does contain a significant amount of oils. The presence of residual oil on the surface of OPEFB is a result of the stripping and threshing process in the mill [33]. In general, the lignocellulosic material of OPEFB has the ability to adsorb and retain certain amount of oil inside and on the surface of its matrix fibre through and adsorption process [34]. The residual oil diffused to the external surface of the fibres, then the migration of oil from the external surface of material to the pores within the fibres, and lastly the oil will remain on the surface of pores [35]. The results showed that extracted residual oil of OPEFB fibre was in the range of 6.13-12.91% in accordance with Yunos *et al.* (2015) [34]. Extracted oil content increased with decreasing fibre size. It was due to the larger surface area of fibres, increasing the amount of oil extracted during the dissolution process. With such amount of oil content on fibre surface, this will disrupt the filler-matrix bonding in biocomposites application. Therefore, in the further studies, surface treatment can be more useful to have a better bonding with matrix.

Table 4 Average of OPEFB fiber dimensions

	Medium-fiber	Short-fiber
Length (L) (µm)	1,535.97	230.12
Diameter (D) (µm)	147.79	58.53
Aspect ratio (L/D)	10.39	3.93
Oil Content (%)	6.13	12.91

Table 5 shows the density of OPEFB fibre, recycled ABS, biocomposites, and glass fibre reinforced composites. Density of OPEFB short-fibre (1.35 g/cm^3) was higher than medium-fibre (0.94 g/cm^3), which means fibre density increased with decreasing of fibre size/aspect ratio. The fibre density values of this work aligned with the results of previous studies which is OPEFB density in the range of 0.7-1.55 g/cm^3 [8, 9, 14, 36, 37].

One of the desirable functions of adding natural fibre on polymeric materials is to reduce the composite mass on account of the inherent low density of the fibre. The density of OPEFB is lower than RABS. Addition of 15 w/w% OPEFB fibre in RABS matrix reduced biocomposite density to 0.958 g/cm^{-3} for RABS/MF and 0.987 g/cm^{-3} for RABS/SF. Although the composition of glass fibre on the composite (10 %) smaller than OPEFB fibre (15%), density of glass fibre filled composites was higher than biocomposites, due to the density of glass fibre is high (2.6 g cm^{-3}) [3].

Table 5 Density of OPEFB fiber and composites

Samples	Density (g cm^{-3})
Medium-fiber	0.938
Short-fiber	1.350
RABS/MF	0.958
RABS/SF	0.987
RABS/GF1	1.123
RABS/GF2	1.105

3.2 Mechanical Properties

3.2.1 Tensile Properties

Figure 1 shows tensile stress-strain relationships for biocomposites and glass fibre filled composites. In general, glass fibre filled composites exhibited more elasticity compared with biocomposites. It can be observed that the tensile strength and elongation at break of biocomposite decreased with decreasing of fibre size.

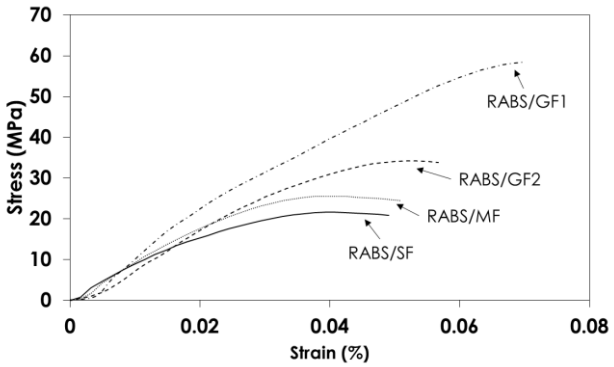


Figure 1 Tensile stress-strain relationship for biocomposites and glass fiber filled composites

Figure 2 illustrates the effect of fibre size filler on the tensile strength of biocomposites. Tensile strength of RABS/SF was higher than RABS/MF, but not significantly different at 95% confidence interval (*P*-value > 0.05). Tensile strength of RABS/GF1 was the highest and

significantly different with RABS/GF2 and biocomposites.

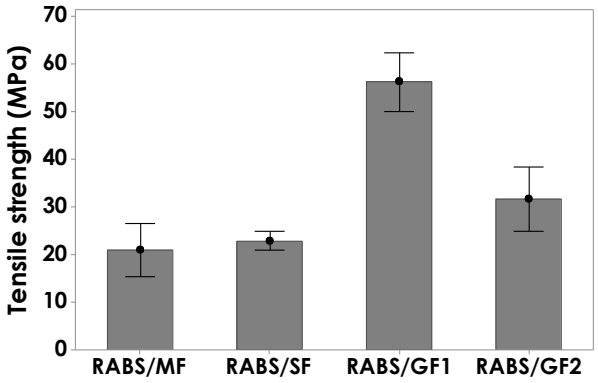


Figure 2 Tensile strength of biocomposites and glass fiber filled composites

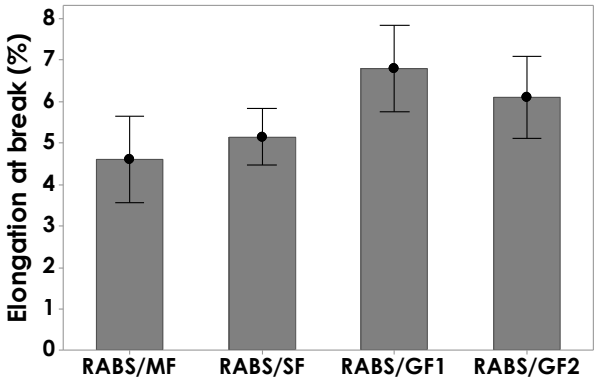


Figure 3 Elongation at break of biocomposites and glass fiber filled composites

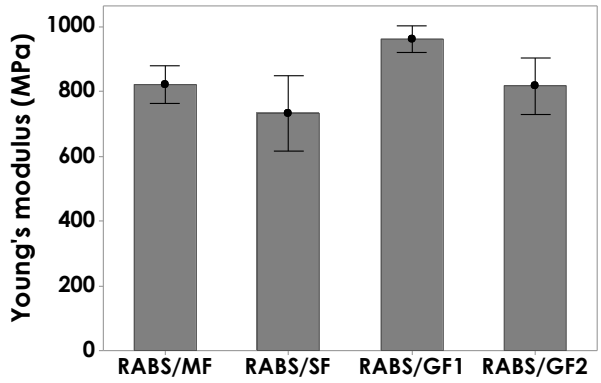


Figure 4 Young's modulus of biocomposites and glass fiber filled composites

As shown in Figure 3, the statistical analysis proved that there are no statistically significant differences in the value of elongation at break for RABS/MF, RABS/SF, RABS/GF1, and RABS/GF2. They are lower than recycled ABS (matrix) was about 16.56 %. Therefore, it can be stated that the filling of fibre as reinforcement decrease of the elongation at break of polymer.

In general, the Young's modulus of a natural fibre is much smaller than that of glass fibre, thus the difference in stiffness between the natural fibre and matrix is smaller than that between the glass fibre and matrix [38]. Figure 4 shows that the decrease in fibre aspect ratio caused decrease in Young's modulus biocomposites, but not significantly different. Young's modulus of RABS/GF1 was the highest, but RABS/SF and RABS/GF2 was no statistically significant differences, which means that RABS/SF has similar stiffness with local glass fibre filled composites.

3.2.2 Impact Strength

The effect of fibre size on the impact strength for notched samples is shown in Figure 5. It can be clearly seen that the impact strength increases significantly with the decreases of OPEFB fibre size as biocomposites filler, similar with previous research [7] which explained that, for OPEFB–PP composite materials where impact strength was found to decrease as the filler size was increased. This was due to higher surface area produced by short-fibre than medium-fibre which may resist the crack propagation. The low aspect ratio of OPEFB may affect their capabilities to support stress transmitted from the ABS matrix. The stiff cellulose fibres will act as stress concentrators in the polymer matrix thus reduce the crack initiation energy and consequently the impact strength of the composites [39].

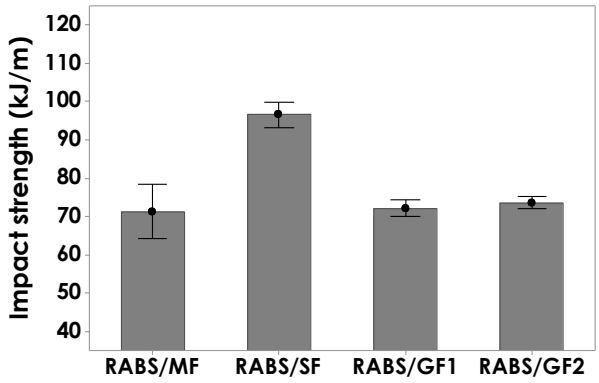


Figure 5 Impact strength of biocomposites and glass fiber filled composites

The impact strength of composites is governed mainly by two factors: first, the capability of the filler to absorb energy that can stop crack propagation and second, poor interfacial bonding which induces micro-spaces between the filler and the matrix, resulting in easy crack propagation [40, 41]. Biocomposites density also affects matrix dependent properties. Tensile strength and Young's modulus vary directly with density. Low density reduces ultimate tensile strengths because at lower densities entrapped air reduces the bond between the fibres and ABS. Therefore, proper compaction of the composite is one of important things.

Furthermore, impact strength or toughness of RABS/SF was the highest, stronger than glass fibre filled composites, either RABS/GF1 or RABS/GF2. This shows that more energy is required to cause failure to the RABS/SF. Main factor that contributes to such improvements was the binding between OPEFB fibre and ABS polymer, assisted also by additives. The fibres play an important function in the impact resistance of the composites as they may interact with the crack formation in the matrix and then act as a stress transferring medium [39]. Addition of fibre as filler in composites, may increase the natural frequency of material so that the ability of a material to resist an external force increases. RABS/SF has a greater impact strength than glass fibre filled composites, which can be interpreted that the biocomposite has a greater natural frequency than the glass fibre filled composites.

The addition of OPEFB fibre has enhanced natural frequencies and damping ratio, due to the large variation in fibre–matrix interface [42]. Relationships can be established between the vibration response of the composite (natural frequency and damping ratio) and energy of impact [43]. Vaidya *et al*. [44] concluded that relationships can be established between the vibration response of the sandwich plate (natural frequency and damping ratio) and energy of impact which mean that more stiff the material, will decreased impact damage. Natural frequency of short-fibre biocomposite higher than synthetic glass fibre composites. This indicates that stiffness of the biocomposite higher than glass fibre composite as the brittleness of biocomposites lower than glass fibre. Consequently, the short-fibre filled biocomposites can absorb higher impact energy.

The ANOVA analysis shows that there are statistically significant differences between the impact strength values of the biocomposites and glass fibre filled composites at 0.05 significant level. As shown in Table 6, the p-value = 0.000 less than the significance level (0.05). It can be concluded that there is a statistically significant difference in the mean of impact strength of RABS/MF, RABS/SF, RABS/GF1 and RABS/GF2.

Table 6 Analysis of variance for impact strength

Source	Degree of Freedom (df)	Sum of square	Mean square	F-value	P-value
Factor	3	2721.2	907.05	41.00	0.000
Error	16	354.0	22.12		
Total	19	3075.1			

Fisher least significant difference (Fisher LSD) method used in ANOVA to create confidence intervals for all pairwise differences between factor level means while controlling the individual error rate to a level specificallt. All pairwise was grouped using a letter, if there were a difference or claimed as significantly different, it would be shown by a different letter; otherwise if there is a likeness or claimed as significantly not different, it would be shown by sharing same letters. Comparison of the impact strength value for all samples and their grouping information by using the fisher LSD method and 95% confidence is presented in Table 7.

Table 7 Grouping information using the fisher LSD method

Factor	N	Mean	Grouping
RABS/SF	5	96.52	A
RABS/GF2	5	73.63	B
RABS/GF1	5	72.15	B
RABS/MF	5	65.67	C

The result showed that RABS/SF has the highest Impact Strength and statistically significant with glass fibre composites and RABS/MFwhere RABS/GF2 and RABS/GF1 was no statistically significant different as group B.

3.3 Surface Properties

3.3.1 Contact Angle Values

Contact angles of the test liquids (water, methanol and hexane) on the biocomposites and glass fibre filled composites as control are given in Table 8. The contact angle represents the wettability of the solid–liquid–vapour system, which indicates the degree of wetting when a solid and liquid interact. Small contact angles (<< 90°) correspond to high wettability and the fluid will spread over a large area on the surface, while large contact angles (>> 90°) correspond to low wettability so the fluid will minimise its contact with the surface and form a compact liquid droplet.

As it can be seen in Table 8, water contact angle of biocomposites is higher than glass fibre filled composites, while hexane contact angle shows reverse trend. This indicates that the surface biocomposite has more hydrophobic than glass fibre composites. Furthermore, the water wettability of RABS/MF is higher than RABS/SF while hexane wettability lower. Which means, the smaller the filler size, the more hydrophobic in the biocomposite.

The measured contact angle values were then used as the SFE calculation by the Young equation (1), which quantifies the wetting characteristics of a solid material. To assess the surface behaviour of biocomposites, water contact angles is more representative used in the calculation of SFE using methods GGFY. For the Owens and Wendt method, water and hexane contact angle were used, while water, methanol, and hexane contact angles all used for vOCG method calculation.

Table 8 Contact angles of the test liquids on the biocomposites

Samples	Contact Angle (°)		
	Water	Methanol	Hexane
RABS/MF	87.86	31.35	11.84
RABS/SF	100.56	37.27	10.55
RABS/GF1	85.75	31.88	13.18
RABS/GF2	85.29	34.17	12.08

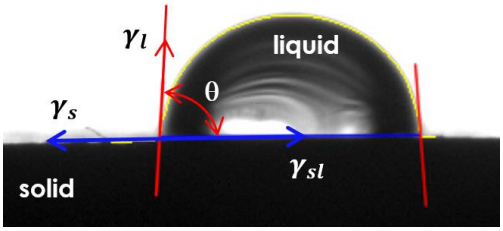


Figure 6 Representative figures of contact angle measurements of RABS/MF. γ_s denotes surface free energy of solid (biocomposites surface), γ_l surface free energy of liquid in contact with the solid, γ_{sl} means the interfacial free energy between the solid and the liquid, and θ is contact angle.

3.3.2 Surface Free Energy Values

biocomposites and their components were calculated using three previous known methods: Girifalco-Good-Fowkes-Young (GGFY), Owen-Wendt, and van Oss-Chaudhury-Good (vOCG). The values of the SFE and its components are presented in Table 9.

SFE component value which computed by GGFY method is γ_s, it means total solid SFE. The γ_s values of biocomposites decreased with decreasing of fibre size, and lower than glass fibre filled composites. The Owen-Wendt method separating the total surface energy value into dispersive (γ_s^d) and polar (γ_s^p) components. Where the superscript *d* indicates the nonpolar contribution to the surface free energy and the polar contribution is $\gamma_s^p = \gamma_s - \gamma_s^d$. The γ_s value of biocomposite showed the same trend as GGFY method, but the dispersive (γ_s^d) components were higher than its polar (γ_s^p) components. In the case of RABS/SF much higher even nine times, which indicates the hydrophobic properties of the material. The biocomposites surface more hydrophobic than glass fibre filled composites.

The latest version of SFE calculation is the vOCG method. SFE is a sum of two components, while the first component γ_s^{LW} is connected with long-range interactions (dispersive, polar and inductive, referred to as Lifshitz-van der Waals electrodynamic interactions) and the second component γ_s^{AB} describes the acid-base interactions. This vOCG method split the polar component (γ_s^{AB}) to the acid (electron-acceptor: γ_s^+) and the base component (electron-donor: γ_s^-), in such a way that $\gamma^{AB} = 2(\gamma^+\gamma^-)^{1/2}$. It can be observed as well from vOCG method calculation values that component of SFE connected with long range interactions is higher than the component describing acid-base interactions γ_s^{AB}. Lewis base (γ_s^-) SFE component was higher than Lewis acid (γ_s^+) for all biocomposites, where Lewis base values of biocomposites decreased with decreasing fibre size filler. Owing to the insignificant γ_s^{AB} value, it may be presumed that these surfaces will show properties of nonpolar materials. This is particularly advantageous due to the application. In general, coating/painting material on ABS polymer composites is oil based (nonpolar). The more hydrophobic biocomposites will increase the wettability and provide better coating by nonpolar/hydrophobic materials.

4.0 CONCLUSION

This study has been demonstrated that the fibre size of filler affects biocomposite mechanical, physical, and surface properties. The result showed that density and impact strength increased with decreasing of OPEFB fibre size, but the Young's modulus decreased. Other mechanical properties (tensile strength, elongation at break) of biocomposites with short-fibre (RABS/SF) and medium-fibre (RABS/MF) filler were not significantly different at 95% confidence interval. High impact strength demonstrated by RABS/SF, higher than glass fibre filled composites. Meanwhile, the elongation at break showed that RABS/SF and RABS/GF1 were not significantly different, and applied the same way to Young's modulus of biocomposites and RABS/GF2. The surface free energy of biocomposites were lower than glass fibre filled composites, but the dispersive component of biocomposites were higher. The smaller the fibre size of biocomposites filler, the higher water contact angles, which means the more hydrophobic the surface. It is advantageous since in general applications, the coating/painting materials for ABS composite were oil based (nonpolar). The more hydrophobic material will result in the better nonpolar coating. Therefore, the short-fibre of OPEFB can be used as viable alternative to replace glass fibre as filler materials of composites.

Acknowledgement

We are grateful for the Indonesia Estate Crop Fund-Oil Palm (Badan Pengelola Dana Perkebunan Kelapa Sawit [BPDPKS]), Ministry of Finance Republic of Indonesia, as funder this work.

Table 9 SFE and its components (in mJ/m²) of recycled ABS and biocomposites calculated with various methods

Samples	GGFY	Owen-Wendt			vOCG				
	γ_s	γ_s	γ_s^d	γ_s^p	γ_s	γ_s^{LW}	γ_s^{AB}	γ_s^+	γ_s^-
RABS/MF	24.18	24.42	18.16	6.26	19.57	18.16	1.41	0.04	11.05
RABS/SF	14.99	20.00	18.09	1.91	18.74	18.09	0.65	0.03	3.13
RABS/GF1	25,92	25,25	17,92	7,33	19,45	17,92	1,53	0,04	13,09
RABS/GF2	26,31	25,51	17,99	7,52	19,31	17,99	1,31	0,03	13,70

References

[1] Indonesia Estate Crop Fund-Palm Oil. 2015. *Annual Report 2015.* Jakarta: Indonesia Estate Crop Fund-Palm Oil.

[2] Directorate General of Agricultural Product Processing and Marketing. 2006. *Pedoman Pengelolaan Limbah Industri Kelapa Sawit*. Jakarta: Ministry of Agriculture Republic of Indonesia.

[3] Shinoj, S., Visvanathan. R., Panigrahi, S. and Kochubabu, M. 2011. Oil Palm Fiber (OPF) and Its Composites: A Review. *Industrial Crops and Products.* 33: 7-22.

[4] Yang, S., Castilleja, J. R., Barrera, E. V. and Lozano, K. 2004. Thermal Analysis of an Acrylonitrile–butadiene–styrene/SWNT Composite. *Polymer Degradation and Stability.* 83: 383-388.

[5] Chen, S. C., Liao, W. H., Hsien, M. W., Chien, R. D. and Lin, S. H. 2011. Influence of Recycled ABS Added to Virgin Polymers on the Physical, Mechanical Properties and Molding Characteristics. *Polymer-Plastics Technology and Engineering.* 50: 306-11.

[6] John, M. J. and Thomas, S. 2008. Biofibres and biocomposites. *Carbohydrate Polymer.* 71: 343-64.

[7] Hassan, A., Salema, A. A., Ani, F. N. and Bakar, A. A. 2010. A Review on Oil Palm Empty Fruit Bunch Fiber-Reinforced Polymer Composite Materials. *Polymer Composites.* 31(12): 2079-2101.

[8] Kalam, A., Sahari, B. B., Khalid, Y. A. and Wong, S. V. 2005. Fatigue Behaviour of Oil Palm Fruit Bunch Fibre/Epoxy and Carbon Fibre/Epoxy Composites. *Composite Structures.* 71: 34-44.

[9] Mahjoub, R., Yatim, J. B. M. and Sam A. R. M. 2013. A Review of Structural Performance of Oil Palm Empty Fruit Bunch Fiber in Polymer Composites. *Advances in Material Science and Engineering.* 2013: 1-9.

[10] Kueh, A. B. H. 2012. Fitting-free Hyperelastic Strain Energy Formulation for Triaxial Weave Fabric Composites. *Mechanics of Materials*. 47: 11-23.

[11] Kam, C. Z., and Kueh, A. B. H. 2013. Bending Response of Cross-ply Laminated Composite Plates with Diagonally Perturbed Localized Interfacial Degeneration. *The Scientific World Journal*. 2013.

[12] Abo Sabah, S. H., and Kueh, A. B. H. 2014. Finite Element Modeling of Laminated Composite Plates with Locally Delaminated Interface Subjected to Impact Loading. *The Scientific World Journal.* 2014.

[13] Kam, C. Z., Kueh, A. B. H., Low, K. B., Wang, X. Y., & Shek, P. N. 2014. Uniaxial Compressive Stability of Laminated Composite Plate with Localised Interfacial Degeneration. *Materials Research Innovations*. 18(sup6): S6-109.

[14] Jawaid, M., Khalil, H. P. S. A. and Bakar A. A. 2010. Mechanical Performance of Oil Palm Empty Fruit Bunches/Jute Fibres Reinforced Epoxy Hybrid Composites. *Material Science and Engineering A.* 527**:** 7944-7949.

[15] Rozman, H. D., Ismail, H., Jaffri, R. M., Animullah, A. and Ishak Z. A. M. 1998. Mechanical Properties of Polyethylene-Oil Palm Empty Fruit Bunch Composites. *Polymer-Plastics Technology and Engineering.* 37(4): 495-507.

[16] Singha, A. S. and Thakur, V. K. 2009. Mechanical and Physical Properties of Biofibers-Based Polymer Composites. *Polymer-Plastics Technology and Engineering.* 48: 736-744.

[17] Nikmatin, S., Syafiuddin, A. and Kueh, A. B. H. 2015. *Jurnal Teknologi.* 77: 181-187.

[18] Nikmatin, S., Syafiuddin, A., Nugroho, N., Utama, W., and Wismogroho, A. S. 2017. Thermo-Physical Properties of Kenaf-Filled Acrylonitrile Butadiene Styrene Composites. *MATEC Web of Conferences*. 95(2017): 03001.

[19] Thomason, J. L. 2002. The Influence of Fibre Length and Concentration on The Properties of Glass Fibre Reinforced Polypropylene: 5. Injection Moulded Long and Short Fibre PP. *Composites: Part A.* 33: 1641-1652.

[20] Nikmatin, S., Syafiuddin, A. and Irwanto, D. A. Y. 2017. Properties of Oil Palm Empty Fruit Bunch-Filled Recycled Acrylonitrile Butadiene Styrene Composites: Effect of Shapes and Filler Loadings with Random Orientation. *BioResources.* 12(1): 1090-1101.

[21] Rozman, H. D., Saad, M. J., and Ishak Z. A. M. 2003. Modification of Oil Palm Empty Fruit Bunches with Maleic Anhydride: The Effect on the Tensile and Dimensional Stability Properties of Empty Fruit Bunch/Polypropylene Composites. *Journal of Applied Polymer Science.* 87: 827-835.

[22] Yusoff, M. Z. M., Salit, M. S. and Ismail, N. 2009. Tensile Properties of Single Oil Palm Empty Fruit Bunch (OPEFB) Fibre. *Sains Malaysiana.* 38(4): 525-529.

[23] Żenkiewicz, M. 2007. Methods For The Calculation of Surface Free Energy of Solids. *Journal of Achievements in Materials and Manufacturing Engineering.* 24(1): 137-145.

[24] Suryadi, G. S. 2017. Kajian Mikrostruktur, Sifat Termal, Mekanik, dan Permukaan Biokomposit Berpenguat Tandan Kosong Kelapa Sawit. Unpublished Master's Thesis. Bogor Agricultural University, Bogor, Indonesia.

[25] Girifalco, L. A. and Good, R. J. 1957. A theory for The Estimation of Surface and Interfacial Energies. *Journal of Physical Chemistry.* 61: 904-909.

[26] Fowkes, F. M. 1964. Attractive Forces at Interfaces. *Industrial & Engineering Chemiatry.* 56(12): 40-52.

[27] Grundke, K. 2005. *Molecular Interfacial Phenomena of Polymers and Biopolymers.* Chapter 10. Cambridge: Woodhead Publishing.

[28] Owens, D. K. and Wendt, R. C. 1969. Estimation of the Surface Free Energy of Polymers. *Journal of Applied Polymer Science.* 13: 1741-1747.

[29] Cwikel, D., Zhao, Q., Liu, C., Su, X. and Marmur, A. 2010. Comparing Contact Angle Measurements and Surface Tension Assessments of Solid Surfaces. *Langmunir.* 26: 15289-15294.

[30] Van Oss, C. J., Chaudhury, M. K. and Good, R. J. 1988. Interfacial Lifshitz-van der Waals and Polar Interactions in Macroscopic Systems. *Chemical Reviews.* 88(6): 927-941.

[31] Young, T. 1805. An Essay on the Cohesion of Fluids. *Philosophical Transactions of the Royal Society of London.* 95: 65-87.

[32] International Association of Wood Anatomists (IAWA). 1989. IAWA List of Microscopic Features for Hardwood Identification; by an IAWA Committee. Eds. Wheeler EA, Baas P, Gasson PE. *IAWA Bull. n.s.* 10(3): 219-332.

[33] Ngan, M. A. 2005. Oil Content in Empty Fruit Bunch. *Palm Oil Engineering Bulletin.* 75: 21-23.

[34] Yunos, N. S. H. M., Baharuddin, A. S., Yunos, K. F. M., Hafid, H. S., Busu, Z., Mochtar, M. N., Sulaiman, S., and Som, A. M. 2015. The Physicochemical Characteristics of Residual Oil and Fibers from Oil Palm Empty Fruit Bunches. *Bio-Resource.* 10: 14-29.

[35] Karan, C. P., Rengasamy, R. S., and Das, D. 2011. Oil Spill Cleanup by Structured Fibre Assembly. *Indian Journal of Fibre and Textile Research.* 36: 190-200.

[36] Sreekala, M. S., George, J., Kumaran, M. G. and Thomas, S. 2002. The Mechanical Performance of Hybrid Phenol-formaldehyde-based Composites Reinforced with Glass and Oil Palm Fibres. *Composites Science and Technology.* 62: 339-53.

[37] Solikhin, A., Hadi, Y. S., Massijaya, M. Y., and Nikmatin, S. 2016. Basic Properties of Oven-Heat Treated Oil Palm Empty Fruit Bunch Stalk Fiber. *BioResources*. 11(1): 2224-2237.

[38] Liang, J. Z. 2016. Predictions of Young's Modulus of Polymer Composites Reinforced with Short Natural Fibers. *Journal of Macromolecular Science, Part B.* 55: 566-574.

[39] Anuar, H., Ahmad, S. H., Rasid, R. and Nik Daud, N. S. 2006. Tensile and Impact Properties of Thermoplastic Natural Rubber Reinforced Short Glass Fiber and Empty Fruit Bunch Hybrid Composites. *Polymer-Plastics Technology and Engineering.* 45: 1059-1063.

[40] Sumaila, M., Amber, I. and Bawa, M. 2013. Effect of Fiber Length on The Physical And Mechanical Properties of Random Oreinted, Nonwoven Short Banana (Musa Balbisiana) Fibre /Epoxy Composite. *Asian Journal of Natural and Applied Science.* 2: 39-49.

[41] Sreenivasan, V. S., Ravindran, D., Manikandan, V. and Narayanasamy, R. 2012. Influence of Fibre Treatments on Mechanical Properties of Short *Sansevieria cylindrica*/polyester composites. *Material and Design.* 37: 111-121.
[42] Rajini, N., Winowlin Jappes, J. T., Rajakarunakaran S, and Jeyaraj, P. 2014. *Journal of Composite Materials*. 47(24): 3105-3121.
[43] Shahdin, A., Morlier, J., Mezeix, L., Bouvet, C., and Gourinat, Y. 2011. Evaluation of the Impact Resistance of Various Composite Sandwich Beams by Vibration Tests. *Shock and Vibration.* 18(2011): 789-805
[44] Vaidya, U. K., Pillay, S., Bartus, S., Ulven, C. A., Grow, D. T., and Mathew, B. 2006. Impact and Post-impact Vibration Response of Protective Metal Foam Composite Sandwich Plates. *Materials Science and Engineering A*. 428 (2006): 59-66.