A review of oil palm fruit fiber reinforced composites

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Abstract. Oil palm fibers have been developed as reinforcement in the composite. These fibers can be produced from fruit, trunk, and frond of oil palm. In this review, the oil palm fruit fiber for reinforcing composite was focused. Oil palm fruit fibers consist of empty fruit bunch (EFB) and mesocarp fruit (MF) fibers. The chemical composition and characteristics of oil palm fruit fiber are described. Furthermore, the mechanical properties of the composite are reported to be related to the surface treatment of EFB and MF fibers. Applications of such fiber composite are included in this review. From some researches, the surface treatment methods for MF and EFB fibers as reinforcement composite was conducted with using alkali, silane, acrylic acid, acetic anhydride, hydrogen peroxide, microwave, and superheated steam. The effect of these surface treatments on oil palm EFB and MF fibers displayed the improvement of the mechanical properties (tensile, flexural and impact strengths) of the composite due to enhance the interface adhesion between fiber and matrix after treatment of fibers.

1. Introduction
Oil palm (*Elaeis guineensis*) is a tropical plant coming from West Africa. It has spread to tropical countries, including Indonesia and Malaysia. Oil palm arrived in Indonesia by the Dutch in 1848, and some seeds were planted in the Bogor Botanical Gardens [2]. Since 1991, Indonesia has planted oil palm commercially [3]. According to the data from the United States Department of Agriculture (USDA) in 2019, Indonesia has the largest area of oil palm plantations, about 11.75 million ha, followed by Malaysia, Nigeria, Thailand, Colombia, Cote D’Ivoire, Ghana, Guinea, Ecuador, Guatemala and produced palm oil about 42.5 million metric tons. The palm oil sector has contributed to the increase in foreign exchange of these countries. From this data, dry by-products of oil palm can be predicted by approximately 170 million tons based on the estimation that production of one metric ton palm oil can generate about 4 tons dry by-products [4-5]. These dry by-products of oil palm are from trunk, frond, and fruit. These can lead to a heavy problem on the environment [6-9] because of the utilization of those has not been seriously considered. It is still focused on the main product of oil palm (crude palm oil (CPO) and palm kernel oil (PKO)) [3]. This problem can be solved by utilizing these by-products for various applications, such as for reinforcement of composite [10].

Natural fibers like ramie, jute, kenaf, coir, and sisal fibers have been used in composite materials as reinforcement. Natural fiber composites are made of fiber component as reinforcement and matrix component as a binder where the fibers used are natural fibers. These composites have been developed as an alternative to change the synthetic fiber composites because natural fibers are low density, abundance, low cost, biodegradability and eco-friendly [11-13]. One of natural fibers which become a concern as filler or reinforcement in the composite is oil palm fiber due to abundant in the area of the oil palm industry. Oil palm fiber can be extracted from trunk, frond, and fruit. The use of palm oil fibers as reinforcement of composite requires surface treatment like the treatment carried out by other natural fibers to improve fiber and matrix compatibility in the composite. This requirement is due to
the hydrophilic property of natural fibers and the hydrophobic property of non-polar polymers [11-13]. The physical and chemical treatments are often used to improve that compatibility. Improving fiber-matrix adhesion in composites consequently enhances the mechanical properties of composites [11,14].

In this paper, the review focuses on oil palm fruit fibers consisting of empty fruit bunch (EFB) and mesocarp fruit (MF) fibers. The influence of fiber surface treatment on the mechanical properties of composites are discussed. Chemical composition and mechanical properties of those fibers are also presented.

2. Chemical Composition and Mechanical Properties of Oil Palm Fruit Fiber

Oil palm EFB fiber is taken from oil palm fruit bunch which extracted by retting method [9]. Retting methods include chemical, heat, mechanical decortication, dew, water and enzymatic methods [9,15]. Those methods have advantages and disadvantages in utilization. According to Tahir et al. [15], water retting can be used to obtain the best quality of fibers; meanwhile, it needs a long time process and also can lead to water pollution. Then, chemical retting can produce cleaner fibers, but it reduced tensile properties of those. Besides, enzymatic retting is a retting process which does not need a long duration for yielding high quality of fibers, but it is the relatively high cost and reduces fiber strength [15-16]. The retting process which is safe to the environment and in a short time produces short fiber in large quantities is mechanical retting; however, it is more expensive for processing and also produces the low quality of fiber [9,16]. Meanwhile, the mesocarp fruit (MF) fiber is the fiber gained from the residual milling of palm fruit oil during crude palm oil production [13].

Like other natural fibers, the main chemical composition of EFB and MF fibers is cellulose, hemicellulose and lignin. Chemical composition of EFB and MF fibers have been studied by some researchers (Table 1). Oil palm fruit fiber (EFB and MF) are lignocellulosic fibers which are binded by lignin with cellulose and hemicellulose as reinforcement [17].

| Table 1. Chemical Composition of oil palm fruit fibers |
|----------------|----------------|----------------|
| Oil Palm Fiber | Chemical composition (%) | Ref. |
|                | Cellulose | Hemicellulose | Lignin |
| EFB             | 42.7-65   | 17.1-33.5     | 13.2-25.31 | [6,8-9,18-19] |
| MF              | 32.2-60   | 21.7-31.62    | 11-23.89   | [6,20-21]     |

Regarding the mechanical properties of EFB fiber, Yousif and El-Tayeb [22-23] have investigated tensile strength, tensile modulus and elongation of untreated and alkali-treated EFB fibers. They obtained results that the tensile strength and tensile modulus before and after alkali treatment of fibers enhanced from 70 MPa to 80 MPa and 0.59 GPa to 1.7 respectively, but elongation reduced from 16.2 % to 14.2%. Then, Gunawan et al. [24] have measured the density, tensile modulus and tensile strength of EFB fiber. They found that the diameter of EFB fiber is various between 0.4 mm and 0.72 mm and influences the tensile strength of fiber where the smaller diameter of fiber, the higher tensile strength of that. The tensile strength of fiber with 0.44 mm diameter is 253 MPa, and the tensile modulus is about 16 GPa.

Furthermore, the tensile modulus and density of mesocarp fruit (MF) fiber based on nut variety are about 1.8 – 3.6 GPa and 1.268 g/cm³ [26], respectively. This fiber has diameter of 0.22 mm for fresh fiber and 0.19 mm for dried fiber [25]. Hanipah et al. [27] have investigated the mechanical properties of MF fiber and found that the higher tensile stress, elongation and tensile modulus of fiber with 0.1 to 0.25 mm diameter are 373 MPa, 0.21 for 1.0 m/s test speeds, and 4.84 GPa for 0.1 m/s test speed, respectively.

The mechanical properties of EFB and MF fiber are competitive to other natural fibers like kenaf, sugar palm, coir, and sisal for reinforcement of polymer composite (Table 2).
Table 2. Comparison of mechanical properties of EFB and MF fibers with other natural fibers

| Fibers    | Tensile strength (MPa) | Tensile modulus (GPa) | Diameter (mm) | Ref. |
|-----------|------------------------|-----------------------|---------------|------|
| EFB       | 253                    | 16                    | 0.44          | [24] |
| MF        | 373                    | 3.87                  | 0.1-0.25      | [27] |
| Kenaf     | 282.6                  | 7.13                  | 0.083         | [28] |
| Coir      | 218.3                  | 6.1                   | -             | [29] |
| Sisal     | 312.5                  | 13.19                 | 0.268         | [30] |
| Sugar Palm| 133.3                  | 3.85                  | 0.22          | [31] |

3. Oil palm fruit fiber composite and its applications

3.1. Oil palm empty fruit bunch (EFB) fiber composite

Oil palm fruit (EFB and MF) fiber composites have been studied by researchers which are related to surface treatment of fiber, including chemical and thermal treatments (Table 3). Chemical treatment of EFB fiber with alkali, silane (γ-Methacryloxypropyltri-methoxysilane (MTS) and vinyltriethoxysilane (VTS)) and acrylic acid has been performed by Arif et al. [11] to improve the mechanical behaviour of high density polyethylene (HDPE) composite. They obtained that tensile strength and modulus of composite increase after 10% NaOH, 3%MTS, 3%VTS and 5% acrylic acid treatments of fibers compared to untreated fibers. The highest tensile strength of the composite is after 3% MTS treatment of fiber. Meanwhile, the highest tensile modulus of the composite is 5% acrylic acid treatment of fiber. Algali and silane treatments of fibers also enhanced flexural strength and flexural modulus of the composite. Then, alkali, silane and acrylic acid treatments can improve the water absorption of the composite, which displayed the water absorption is reduced after these treatments. Dhandapani et al. [12] has also studied the effect of alkali, silane and acetic anhydride treatments of EFB fibers on mechanical, thermal and morphological properties of EFB fiber/polyester composites. Tensile strength, tensile modulus, flexural strength and flexural modulus of the composite enhanced after alkali, silane and acetic anhydride treatments due to excellent adhesion between the fiber and matrix [12]. The highest tensile and flexural strengths of the composite are 28.11 MPa for silane treatment and 46.15 MPa for acetic anhydride treatment, respectively. Then, EFB fiber-polyester composite after alkali (6% NaOH) treatment of fiber showed better wear property than untreated fiber [23]. Anggawan and Mohamad [32] investigated the various concentration (2%, 5% and 10%) of alkali (NaOH) treatment of EFB fiber for reinforcing composite. The 2% NaOH treatment of EFB fiber was the best concentration of NaOH for improving tensile and thermal properties of the composite.

Moreover, hydrogen peroxide treatment of EFB fiber and addition of coupling agent was obtained by enhancing the tensile and flexural strength of composite due to the improvement of interfacial adhesion of fiber-matrix [33]. The similar hydrogen peroxide treatment of EFB fiber was employed by Rayung et al. [34] for reinforcing poly(lactic acid) composite. The improvement of mechanical properties of EFB/PLA composite was obtained after this treatment. In addition, surface treatment of EFB fiber with acetic, propionic and succinic anhydride was found that it can increase the physical and mechanical properties of EFB fiber-polyester composite [10].

Table 3. The mechanical properties of EFB and MF fibers composites at different surface treatment of fibers

| Property       | Surface treatment | Composite | Value | Ref. |
|----------------|-------------------|-----------|-------|------|
| Tensile strength | Untreated        | EFB/HDPE  | ~21   | [11] |
|                | NaOH(10%)         |           | ~21   |      |
Beside chemical treatment of EFB fiber, heat treatment of fiber was also conducted to improve physical and mechanical properties of the composite. Heat treatment of EFB fiber at 180°C influenced the resistance of EFB fiber-high density polyethylene composite on the soil burial and indoor environment condition. Mechanical and thermal properties of untreated fiber composite are moderately lower than treated fiber composite after soil burial conditioning effect [35]. Then, microwave treatment has also used to modify the surface of EFB fiber for reinforcement of hybrid composite [14]. This treatment was combined by 12.5% NaOH solution where fiber was immersed in this solution in the microwave oven at 70, 80 and 90°C for 60 minutes and at 90°C for 60, 90 and 120 minutes.

| (MPa)                  | Silane (3%)  | Acryilic acid (5%) | Untreated                           | NaOH | Silane | Acetic anhydride | EFB/Polyester | 25.61 | 28.11 | 25.49 | [12] |
|-----------------------|--------------|--------------------|-------------------------------------|------|--------|------------------|---------------|--------|--------|--------|------|
|                       |              |                    | Untreated                           | NaOH | Silane | Acetic anhydride | EFB/Polyester | 11.24  | 21.88  |        | [32] |
|                       |              |                    | Untreated                           | Hydogen peroxide | Polypropylene | 28.3 | Polypropylene | 39.5 | [14] |
|                       |              |                    | Untreated                           | Microwave-alkali | Polypropylene | 13.86 | MF/PBS         | 23.44 | [13] |
|                       |              |                    | Untreated                           | Alkaline-peroxide | MF/PBS | 13.86 | 21.39 | [20] |
|                       |              |                    | Untreated                           | NaOH (10%) | Silane | Acrylic acid (5%) | EFB/HDPE | ~34    | ~36    | ~37   | [11] |
|                       |              |                    | Untreated                           | EFB/Polyester | 40.97 | 46.10 | 46.15 | [12] |
|                       |              |                    | Untreated                           | Hydogen peroxide | Polypropylene | 46.10 | 46.15 |        | [33] |
|                       |              |                    | Untreated                           | Microwave + alkali | Polypropylene | 23.5 | 33.3 | [14] |
|                       |              |                    | Untreated                           | Alkaline-peroxide | MF/PBS | 27.25 | 31.04 | [20] |
|                       |              |                    | Untreated                           | NaOH | Silane | Acetic anhydride | EFB/Polyester | 19.49  | 31.22  | 34.71  | 30.81 | [12] |
|                       |              |                    | Untreated                           | Hydogen peroxide | Polypropylene | ~42  | ~49 | [33] |
|                       |              |                    | Untreated                           | Alkaline-peroxide | MF/PBS | 65.75 | 82.19 | [20] |

Impact strength (J/m)

| (MPa)                  | Silane (3%)  | Acryilic acid (5%) | Untreated                           | NaOH | Silane | Acetic anhydride | EFB/Polyester | 19.49  | 31.22  | 34.71  | 30.81 | [12] |
|-----------------------|--------------|--------------------|-------------------------------------|------|--------|------------------|---------------|--------|--------|--------|------|
|                       |              |                    | Untreated                           | NaOH | Silane | Acetic anhydride | EFB/Polyester | 19.49  | 31.22  | 34.71  | 30.81 | [12] |
|                       |              |                    | Untreated                           | Hydogen peroxide | Polypropylene | ~42  | ~49 | [33] |
|                       |              |                    | Untreated                           | Alkaline-peroxide | MF/PBS | 65.75 | 82.19 | [20] |
minutes. Its result showed that the EFB fiber treatment at 90°C for 90 minutes has higher mechanical properties (tensile, flexural and impact strengths) of EFB fiber/glass fiber (GF) hybrid composite than others. Related to thermal properties, EFB fiber and treated EFB fiber increase the melting point of composites.

3.2. Oil palm mesocarp fruit (MF) fiber composite
Oil palm mesocarp fruit (MF) fiber has been used as reinforcement in composite with linear low-density polyethylene as a matrix [36]. The improvement of tensile modulus and hardness of composite took place when weight fraction of fibers increase in the composite, but tensile strength, impact strength and strain of composite reduced. Then et al. [13] studied surface modification of oil palm MF fiber with superheated steam treatment followed by various NaOH composition treatment for reinforcement of poly(butylene succinate) (PBS) composite. Their results displayed that the mechanical properties of composite enhanced after treatment of MF fiber compared to untreated fiber. The highest tensile strength and strain of composite were 23.44 MPa and 3.40% respectively after fiber treatment with the combination of superheated steam and 2%NaOH for 3 h soaking time, whereas the highest elastic modulus of composite was 700.60 MPa after fiber treatment with combination of superheated steam and 2%NaOH for 1 h soaking time. Other work on MF fiber with alkaline peroxide treatment found that its treatment can improve the mechanical properties like tensile, flexural and impact strengths of poly(butylene succinate) composite [20]. The improvement of tensile, flexural and impact strengths achieved about 54%, 14%, and 25% respectively compared to untreated MF fiber of composite (Table 3). Then, the surface of oil palm MF fiber was modified by methacrylate silane for improving fiber-matrix interface bonding in hybrid composite [37]. Its hybrid composite is composed to clay, MF fiber, polylactic acid (PLA) and polycaprolactone (PCL). Treated MF fiber hybrid composite has higher mechanical properties than untreated MF fiber hybrid composite.

3.3. Application of oil palm fruit fiber composite
The natural fiber composites have been applied in automotive, construction and furniture, and packaging. Henry Ford firstly introduces the use of natural fiber composite for producing the automotive component in the 1940s followed by the East German Trabant, Daimler-Benz and Mercedes [38]. Regarding oil palm fiber, this fiber has been utilized as reinforcement of polymer composite for automotive application by Proton Car (car producer from Malaysia) [17]. Then, EFB fiber for furniture application has been described by Suhaily et al. [39]. Such fiber has been fabricated in medium density fiberboard (MDF) which is usually used for furniture. MDF from this fibers is very competitive with plywood, particleboard and hardboard [39]. In addition, this fiber has also been applied in particle boards, plywood, and hybrid composite [17]. The utilization of EFB fiber composite has a great potential in the structural building like EFB fiber as reinforcement of concrete roof slates [40]. Momoh and Osofero [18] have studied EFB fiber as reinforcement of cement composite and concluded that its composite has the potential application for building materials like bricks, roofing tiles, building cladding and facades. Also, oil palm fiber composite was used for windows, door frames, panel and so on [41].

4. Conclusions
Oil palm fruit fibers consist of EFB and MF fibers. The EFB fiber can be extracted from oil palm fruit bunch by retting method, and MF fiber can be acquired from the crude palm oil extraction of palm fruit oil. These fibers have mechanical properties that are relatively similar to other natural fibers used as composite reinforcement. The use of these fibers as reinforcement in composites requires surface treatment to increase the interface bonding between fiber and matrix, consequently improving the mechanical properties of the composite. Researchers have found that surface treatments (chemical and physical treatments) of EFB and MF fiber can improve mechanical properties, including tensile, flexural, and impact strengths). Based on this, these fibers have the potential to be developed as a reinforcement for composites in various applications like other natural fiber composites.
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**Acknowledgments**

The authors would like to thank to Engineering Faculty Tadulako University for funding support to oil palm fruit fiber composite research project.