(p-issn: 2089-8630) Journal Science and Technology Tadulako (e-issn: 2962 5696)
Jurnal Sains dan Teknologi Tadulako

DOI: https://doi.org/10.22487/jstt.v12i1.1050

THE EFFECT OF FIBER VOLUME FRACTION IN OIL PALM EMPTY FRUIT BUNCH COMPOSITES ON TENSILE AND IMPACT PROPERTIES

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Abstract
This study aims to analyse the effect of the fiber weight fraction of oil palm empty bunch fiber (OPEBF) composite with HDPE matix on tensile strength and impact. The composite fabrication process is performed using the hot compression method for 210°C with a weight fraction of 40, 50, and 60% fiber. The results showed that the highest tensile strength of the composite fraction of 40% fiber was 3.461 MPa and its modulus of elasticity was 97.702 MPa, followed by the fraction of 50% fiber with a value of 2.948 MPa, the modulus of elasticity was 88.544 MPa, and the lowest value was in the fraction of 60% fiber with a value of 2.205 MPa, and the modulus of elasticity was 87.622 MPa. Furthermore, the highest effort in the impact test on the weight fraction of 40% fiber is 4,249 Joules and an impact energy value of 8364,744 Joules/mm2, followed by a weight fraction of 50% fiber with an effort value to break the specimen of 3,935 Joules and an impact energy value of 7745,651 Joules/mm2, and the lowest attempt to break the specimen at the weight fraction of 60% fiber has a value of 3,341 Joules and has an impact energy of 6576,934 Joules/mm^2.

Key words: *Tensile strength, impact strength, weight fraction, HDPE, and TKKS fiber.*

1. Introduction

Indonesia is one of the world's largest producers of oil palm. Consequently, the volume of both production and waste generated is substantial. Oil palm waste is often discarded and left to pollute the environment (Siahaan & Darianto, 2020). Indonesia is among the largest oil palm plantation producers globally. According to the Central Bureau of Statistics (BPS), in 2024 Indonesian oil palm plantations covered an area of 16,013,039 ha with crude palm oil (CPO) production of 45,436,197 tons per year. These figures indicate a considerable quantity of empty fruit bunch (EFB) waste generated (BPS Indonesia, 2021).

Environmentally friendly waste management systems are necessary to address palm oil mill waste. Currently, most mills use fibers and shells as boiler fuel to generate electricity. In contrast, empty fruit bunches (EFB) represent the largest fraction of solid waste produced by palm oil mills and remain underutilized. Given the scale of crude palm oil production, the amount of EFB waste is substantial (Harefa et al., 2025).

The National Waste Management Information System (SIPSN) reports that plastic waste is the second largest waste type at 19.1%. Household waste is the largest source and is of particular concern because it is difficult to degrade naturally. To prevent further environmental damage, plastic waste must be addressed promptly. The physical properties of HDPE allow it to be used as a binder material

Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026

for EFB fiber boards. (KLH and Forestry, 2021). Both EFB and plastic waste pose significant environmental hazards; one mitigation approach is recycling EFB and plastic waste into new materials intended to replace metal and non-metal materials (Cut, 2024).

Composite constituents can originate from recycled or waste materials such as plastics, sawdust, wood offcuts, bamboo, oil palm residues, etc. A composite comprises a matrix, fibers, and other fillers (Wibowo et al., 2021). In fiber-reinforced composites, the reinforcing phase—fibers—provides enhanced mechanical properties, notably higher tensile strength. Utilization of oil palm empty fruit bunch (EFB) fibers for value-added products is therefore promising (Setiawan et al., 2021).

Fiber-reinforced composites are among the most important materials today due to distinctive properties such as high corrosion resistance, high strength-to-weight and modulus-to-weight ratios, and improved fatigue resistance. Fiber-reinforced polymer (FRP) composites have gained widespread popularity (Yashiro et al., 2019). Using manual lay-up with multiple layers, epoxy hybrid composites reinforced with EFB fibers have been produced. Universal testing machine results indicate that layer configuration affects the tensile strength of hybrid composites, suggesting potential applications in automotive, aerospace, and construction sectors (Amir et al., 2019).

2. Materials and Methods

2.1. Material

1. Oil Palm Empty Fruit Bunch Fiber (EFB fiber)
2. High-Density Polyethylene (HDPE) — a thermoplastic used as the matrix or binder for EFB fibers in the composite.
3. Natrium Hidroksida (NaOH)

2.2. Data

The data used include:

1. Density of EFB and HDPE.
2. Characteristics of EFB and HDPE.
3. Molding temperature during pressing (210°C).
4. Pressing pressure (4 Ton).
5. Volume fractions (40%, 50%, and 60%).
6. Sieving with Mesh 60.

2.3. Methods

The principal steps were as follows:

1. Collection of empty fruit bunches.
2. Fiber separation and cleaning.

Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026

3. Separation was performed by soaking the bunches for 2 hours and then draining. Subsequently, fibers were soaked in a sodium bicarbonate (NaOH) solution to remove impurities and lignin.
4. Drying of EFB fibers to remove moisture content.
5. Comminution of fibers into powder using a blender after separation.
6. Sieving the resulting powder to obtain particles of uniform size corresponding to mesh 60.
7. Composite fabrication and specimen preparation by hot compression molding at the specified temperature and pressure for the designated fiber fractions.
   - Mechanical Testing

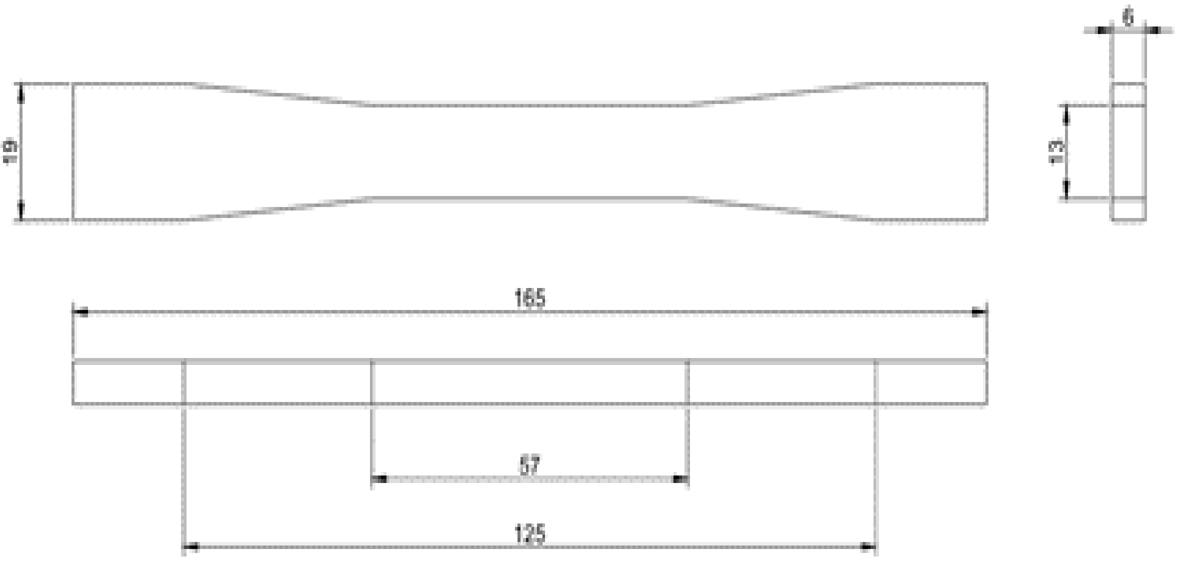

Figure 1. ASTM D 638 tensile test

- **Impact testing** following ASTM D 611 standard.

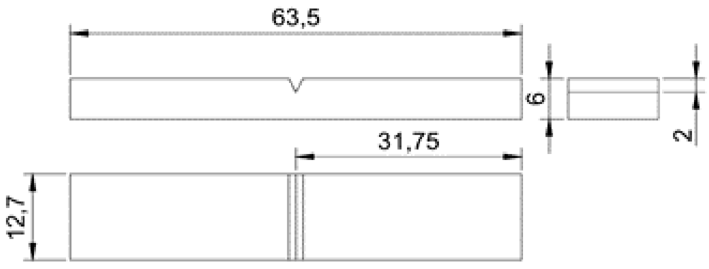

Figure 2. ASTM D 611 impact test standard

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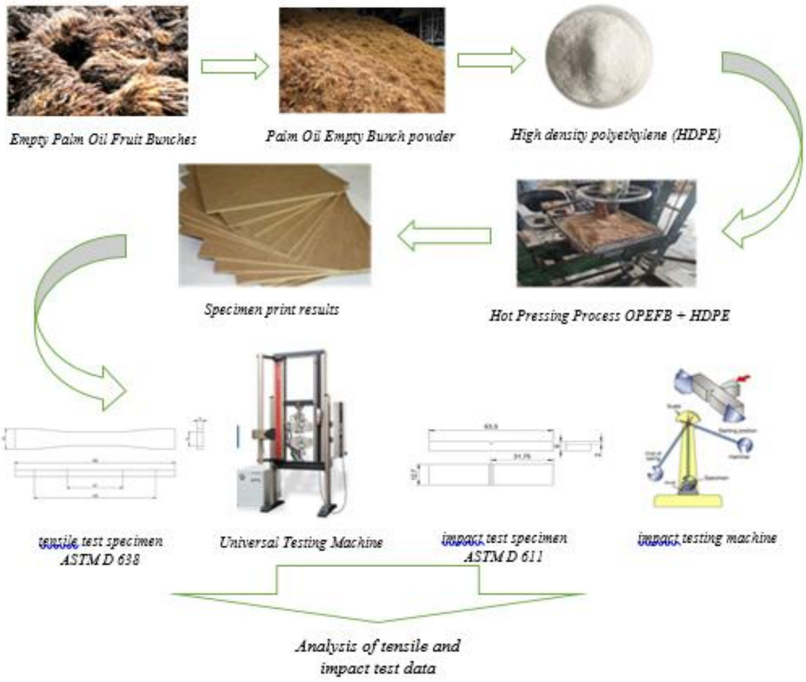

Figure 3. Composite fabrication process for EFB + HDPE

3. Literature Review

3.1. Oil Palm Empty Fruit Bunch (EFB)

Oil palm is a major agricultural commodity in Indonesia and is the primary source of crude palm oil (CPO) and palm kernel oil (PKO). However, EFB waste is increasing, and many palm oil companies have yet to utilize this waste stream. Palm oil production generates significant waste, and one novel approach to manage EFB waste is to produce composite films from pulp processed from EFB (Haqiqi et al., 2021).

Figure 4. Empty fruit bunch and fibers

The largest quantity of empty bunch waste is produced from processing Fresh Fruit Bunches (FFB) after tipper and sterilizer operations, accounting for 23% of production, with cellulose content of 41.3%–46.5% $(C_6H_{10}O_5)_n$, hemicellulose 25.3%–32.5%, and lignin 27.6%–32.5% (Hosseini Rahdar & Nasiri, 2020). These constituents give EFB waste potential as an energy source (Srasri et al., 2022).

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3.2. High-Density Polyethylene (HDPE*)*

High-density polyethylene (HDPE) is produced in reactors under low-pressure aqueous conditions. Catalysts typically derive from modified silica–alumina with metal oxides such as chromium oxide or molybdenum oxide, or Ziegler-type catalysts such as Al(C2H5)3 and α-TiCl4 complexes. Although reaction conditions are generally mild, HDPE polymerization varies across procedures. In fluidized-bed reactors, polymer particles grow as ethylene and comonomers are introduced. Typical operating conditions include pressures around 20 atm and temperatures near 100°C. The fluidization gas removes some of the exothermic reaction heat. The reactor product is mixed with additives and then discharged. Phase-change and slurry systems with hydrocarbon diluents are also used. Due to the absence of branching, HDPE exhibits higher crystallinity and melting temperature than LDPE; hydrocarbon diluents are required in some systems (Zulnazri et al., 2020).

Table 1. Physical Properties of LDPE and HDPE

Physical Property	**LDPE**	**HDPE**
Melting Point (°C)	105 - 115	125 - 130
Degree of Crystallinity (%)	65	85 – 95
Specific Gravity (g/cm³)	0,91 – 0,92	0,95 – 0,96
Softening Point (°C)	105	124
Compressive Strength (Kgf/cm²)	144	245
Elongation (%)	500	100
Hardness (Rockwell)	60	65
Tensile Strength (MPa)	11 – 27	16 - 45

Source: (Zulnazri et al., 2020)

3.3. Mesh

Mesh size denotes the number of openings per square inch of a screen or sieve through which solid material can pass. For example, mesh 20 indicates 20 openings per square inch; mesh 4 indicates 4 openings per square inch. Micron size and mesh are inversely correlated: larger micron values correspond to smaller mesh numbers and coarser filtration.

4. Results and Discussion

4.1 Tensile Strength Testing

Tensile tests were conducted according to ASTM D 638-I (see Figure 3). The tests recorded stress, strain, and elastic modulus data. Composites were prepared with fiber/HDPE weight fractions of 40/60, 50/50, and 60/40, and data were collected for specimens molded at 210°C.

Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026

Table 2. Calculated tensile strength and elastic modulus for EFB fiber–HDPE composites

Tensile Stress (MPa)	**Elastic Modulus (MPa)**	**Description**
2,205	87,623	Fiber volume fraction 40% : HDPE 60%
2,949	88,545	Fiber volume fraction 50% : HDPE 50%
3,462	97,702	Fiber volume fraction 60% : HDPE 40%

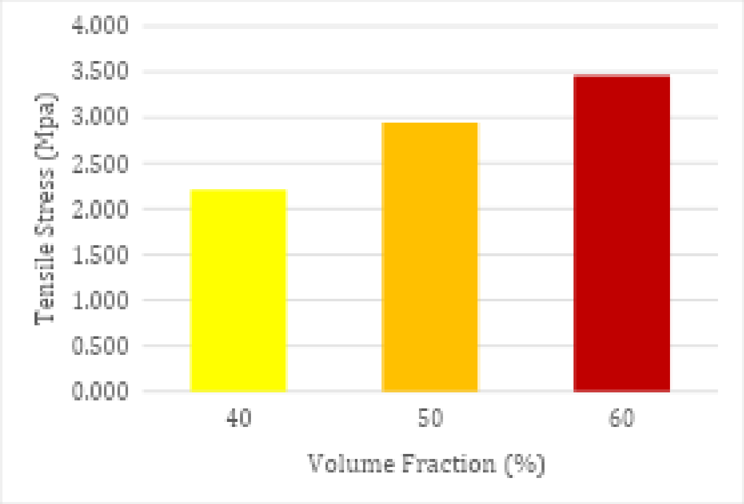

Figure 5. Tensile strength versus volume fraction

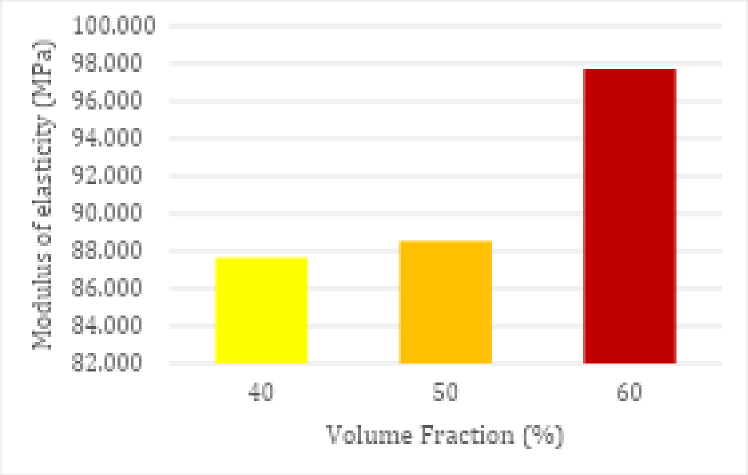

Figure 6. Elastic modulus versus volume fraction

The mechanical properties of the composite, particularly tensile strength and elastic modulus, are significantly influenced by increasing the EFB fiber volume fraction in the HDPE matrix (see Figures 5 and 6). Tensile strength increased from 2.205 MPa at 40% fiber volume fraction to 2.949 MPa at 50% and reached a maximum of 3.462 MPa at 60% fiber volume fraction. This trend indicates that higher fiber content enhances the matrix's ability to transfer load to the EFB fibers, demonstrating the dominant reinforcing role of the fibers.

Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026

The elastic modulus increased from 87.623 MPa (40%) to 88.545 MPa (50%) and 97.702 MPa (60%), following a similar trend and indicating improved stiffness and resistance to deformation at higher fiber fractions. This behavior can be attributed to enhanced fiber–matrix interfacial interactions and the inherently stiffer lignocellulosic fibers, which reduce the influence of the ductile HDPE matrix. Overall, within the investigated range, the composite composition with 60% fiber volume fraction yielded the best mechanical performance, although excessively high fiber contents may cause dispersion and interphase bonding issues if not properly controlled.

4.2 Impact Testing

Impact test results based on weight fraction are presented below:

Table 3. Impact test results for EFB fiber–HDPE composites

Impact Energy (Joule)	Impact Value (Juole/mm^2)	Description
0,0493	972,283	Fiber volume fraction 40% : HDPE 60%
0,0791	1558,74	Fiber volume fraction 50%: HDPE 50%
0,1019	2006,3	Fiber volume fraction 60% :HDPE 40%

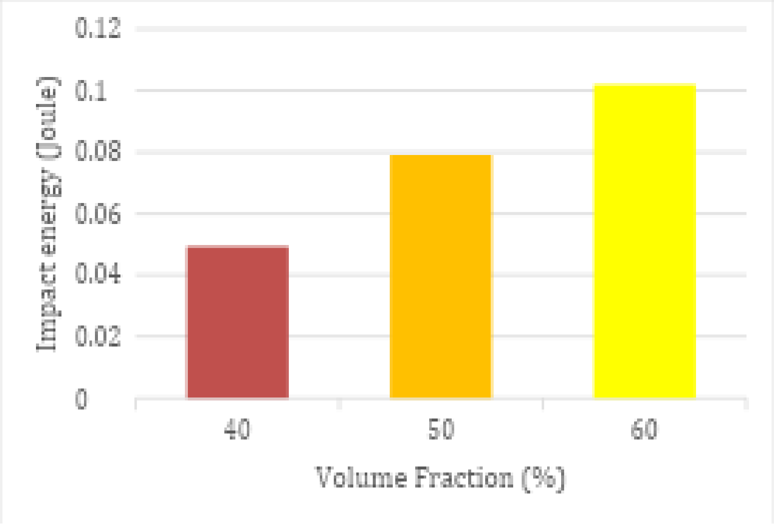

Figure 7. Impact energy versus volume fraction.

Increasing the EFB fiber volume fraction in the HDPE matrix significantly affected both impact energy and impact value, as shown in Figures 7 and 8. Impact energy rose from 0.0493 J at 40% fiber volume fraction to 0.0791 J at 50% and reached 0.1019 J at 60%. This indicates that the composite's capacity to absorb impact energy improves with higher fiber content. The EFB fibers contribute to energy absorption mechanisms such as microcracking, fiber pull-out, and more controlled crack propagation, thereby mitigating brittle failure

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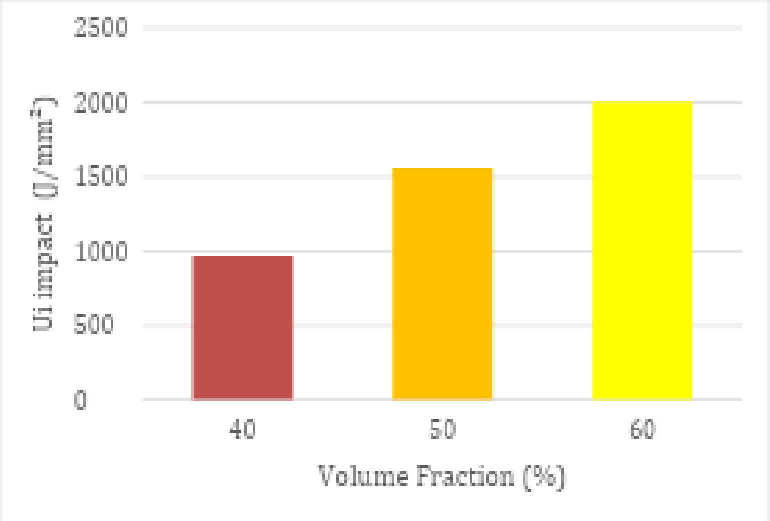

Figure 8. Ui value from impact test versus volume fraction

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The impact value also increased markedly from 972.383 J/m² (40%) to 1,558.74 J/m² (50%) and 2,006.3 J/m² (60%), indicating enhanced material toughness. These results suggest that improved fiber–matrix distribution and interfacial bonding at higher fiber fractions enhance the composite's resistance to shock loading. Overall, HDPE matrices reinforced with up to 60% EFB fiber volume fraction demonstrated superior energy absorption and impact resistance, making them suitable for applications requiring improved impact toughness.

5. Conclusion

In tensile testing, increasing the fiber volume fraction from 40% to 60% raised tensile strength from 2.205 MPa to 3.462 MPa and elastic modulus from 87.623 MPa to 97.702 MPa. These tensile test results indicate that increasing the fiber volume fraction significantly enhances the composite's mechanical properties.

In impact testing, the EFB fiber volume fraction also increased the composite's impact performance. Impact energy rose from 0.0493 J at 40% fiber to 0.1019 J at 60%, and the impact value increased from 972.383 J/m² to 2,006.3 J/m². Mechanisms such as fiber pull-out, microcracking, and more controlled crack propagation contribute to improved energy absorption and toughness. Overall, within the studied range, the EFB–HDPE composite with a 60% fiber volume fraction provided the best combination of tensile strength, elastic modulus, and impact resistance. With appropriate control of fiber dispersion and interfacial bonding quality, this composite formulation can be applied to products requiring enhanced mechanical strength and toughness.

Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026

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Received December 25, 2025, Revised April 17, 2026, Accepted for publication April 20, 2026