**JURNAL INTEGRASI PROSES**

**Website: http://jurnal.untirta.ac.id/index.php/jip**

***Submitted : 23 August 2024*** ***Revised : 10 October 2024*** ***Accepted : 29 November 2024***

# THE EFFECT OF OIL PALM EMPTY FRUIT BUNCH (OPEFB) FILLER ON THE IMPACT STRENGTH, SURFACE MORPHOLOGY, AND THERMAL PROPERTIES OF HIGH IMPACT POLYSTYRENE (HIPS)/OPEFB COMPOSITES

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**Abstrak**

Penelitian ini mengkaji pengaruh filler Tandan Kosong Kelapa Sawit (TKKS) terhadap sifat mekanik dan termal komposit High-Impact Polystyrene (HIPS). Polimer HIPS, yang dikenal karena ketahanan impaknya, dikombinasikan dengan filler TKKS untuk dikaji perubahan yang terjadi terhadap kekuatan impak, suhu transisi kaca ($T_g$), suhu leleh ($T_m$), entalpi pelelehan ($\Delta H_m$), dan morfologi permukaan. Komposit HIPS/TKKS, dengan variasi persentase TKKS 0%b, 10%b, 15%b, dan 20%b, disiapkan menggunakan *Compounder* dan *Manual Forming Machine*. Pengujian kekuatan impak dilakukan dengan metode Charpy *unnotched*, sementara pengujian morfologi serta sifat termal dilakukan menggunakan *Scanning Electron Microscope* (SEM) dan *Differential Scanning Calorimetry*. Hasil pengujian menunjukkan penurunan kekuatan impak seiring dengan meningkatnya kandungan TKKS yang disebabkan oleh lemahnya ikatan antarmuka antara matriks HIPS yang bersifat hidrofobik dan filler TKKS yang bersifat hidrofilik. Analisis termal menunjukkan penurunan $T_g$, $T_m$, dan $\Delta H_m$ yang mengindikasikan perubahan pada kristalinitas dan mobilitas rantai polimer akibat penambahan filler TKKS pada matriks HIPS. Observasi morfologi permukaan menunjukkan adanya pori-pori ukuran besar dan tidak merata, terutama pada pengisian TKKS yang lebih besar, yang berkontribusi pada penurunan performa kuat impak komposit. Penelitian ini memberikan wawasan signifikan mengenai penggunaan TKKS tanpa modifikasi sebagai filler dalam komposit HIPS. Penelitian ini mengungkap tantangan yang timbul akibat sifat hidrofilik filler TKKS dan dampaknya terhadap sifat termal dan mekanik komposit HIPS/TKKS. Temuan ini menekankan pentingnya peningkatan kompatibilitas antarmuka untuk mendukung pengembangan material komposit HIPS/TKKS yang berkelanjutan dan ekonomis.

**Kata Kunci**: HIPS; Kekuatan impak; Komposit; Sifat termal; TKKS

***Abstract***

*This study investigates the effect of Oil Palm Empty Fruit Bunch (OPEFB) filler on the mechanical and thermal properties of High-Impact Polystyrene (HIPS) composites. HIPS, known for its impact resistance, was combined with OPEFB filler to evaluate the changes in impact strength, glass transition temperature ($T_g$), melting temperature ($T_m$), melting enthalpy ($\Delta H_m$), and surface morphology. HIPS/OPEFB composite, with OPEFB filler percentages of 0%wt, 10%wt, 15%wt, and 20%wt, were prepared using a Compounder and Manual Forming Machine. The impact strength test was conducted using the Charpy unnotched method, while the morphological and thermal properties were analyzed using Scanning Electron Microscopy (SEM) and Differential Scanning Calorimetry (DSC). The results showed decreased impact strength with increasing OPEFB content due to weak interfacial bonding between the hydrophobic HIPS matrix and the hydrophilic OPEFB filler. Thermal analysis revealed a reduction in $T_g$, $T_m$, and $\Delta H_m$, indicating changes in crystallinity and polymer chain mobility due to the addition of OPEFB filler in the HIPS matrix. Surface morphology observations revealed the presence of large and unevenly distributed pores, especially with higher OPEFB percentages, contributing to the decreased impact strength performance of the composites. This study provides significant insights into untreated OPEFB filler in HIPS composites. It highlights the challenges posed by the hydrophilic nature of OPEFB fillers and its impact on the thermal and mechanical properties of HIPS/OPEFB composite. These findings emphasize the importance of improving interfacial compatibility to advance the development of sustainable and cost-effective HIPS/OPEFB composite materials.*

***Keywords**: Composite; HIPS; Impact strength; OPEFB; Thermal properties*

## 1. INTRODUCTION

High-impact polystyrene (HIPS) is a multiphase material that consists of a rigid polystyrene (PS) matrix with dispersed polybutadiene (PB) rubber particles, which improve the HIPS impact resistance. This dual-phase system, which includes a rubber phase and a continuous polystyrene phase, makes HIPS used in numerous applications such as packaging, containers, appliance parts, household items, automobiles, transportation, and electronic equipment (Giakoumakis et al., 2024; Liu et al., 2015). HIPS is a widely used thermoplastic material due to its desirable properties, such as impact resistance and rigidity. There are ongoing efforts to improve HIPS properties like heat resistance, which could broaden its usability further in an extensive range of temperatures (Liu et al., 2014; Sun et al., 2022). One method of improving the properties of HIPS is to combine its superior characteristics with those of another material to make a composite.

This versatility makes HIPS an excellent candidate for composite material manufacturing, where combining its properties with fillers can enhance performance and meet specific application demands, such as those in the automotive industry. Automobile composite materials offer significant advantages over conventional materials due to their high durability, strength, lightweight properties, and corrosion resistance, enhancing ballistic performance (Khan et al., 2024). In composite manufacturing, fillers are often used in the polymer matrix for various reasons, such as cost reduction, thermal stability, flame retardancy, and improved mechanical properties, such as hardness and tear resistance. One of the fillers that has become popular nowadays due to its sustainability is a natural filler derived from plants or animals.

Synthetic additives are widely used to reinforce composite materials. Still, their drawbacks, including toxicity, higher costs, and environmental pollution during production, have prompted researchers to explore natural materials as a more sustainable alternative (Rama Rao & Ramakrishna, 2022). The Oil Palm Empty Fruit Bunch (OPEFB) is a promising natural filler alternative in Indonesia. Indonesia produces 7 million tons of OPEFB annually (Anita et al., 2020). Indonesia's massive agro-industrial sector produces large volumes of OPEFB, which has a detrimental environmental impact but offers significant potential for use as raw materials for bioenergy and composites (Aguilar et al., 2022; Suhartini et al., 2022). It was found that lignocellulosic materials, which are lignin, cellulose, and hemicellulose, were the primary components of the OPEFB, with cellulose being the most abundant (Aguilar et al., 2022). In recent years, lignocellulosic fibers have been increasingly utilized as reinforcements in thermoset and thermoplastic matrices to create affordable, lightweight materials for construction, automotive components, and consumer products, driven by rising environmental concerns.

Previous studies have demonstrated that incorporating OPEFB into various polymer matrices can enhance mechanical and thermal properties. For instance, adding OPEFB to a thermosetting matrix has improved mechanical integrity and acoustic absorption (Bakri et al., 2015). OPEFB also enhances the thermal properties of both thermoset and thermoplastic polymer composites (Saba et al., 2017). Furthermore, the following study found that acrylonitrile butadiene styrene (ABS) composites with nano powder OPEFB fillers become more elastic and exhibit improved impact and hardness properties as the filler loading increases (Nikmatin et al., 2017). Thus, assessing the properties of HIPS composite with OPEFB as filler is essential to optimize performance, sustainability, cost-efficiency, and market demand for green products. Unlike prior studies that modified the compatibility of Oil Palm Empty Fruit Bunch (OPEFB) with High-Impact Polystyrene (HIPS) through chemical modifications such as grafting polystyrene onto OPEFB (Jamaluddin, 2005), this research directly incorporates untreated OPEFB into the HIPS matrix.

This research aims to investigate the effects of untreated OPEFB filler on the thermal properties, impact strength, and morphology of HIPS composites. This approach aims to address the challenges of interfacial bonding and crystallinity due to the hydrophilic nature of OPEFB, which inherently contrasts with the hydrophobic HIPS matrix. By examining the impact of untreated OPEFB on HIPS, this study seeks to provide valuable insights into the development of more straightforward and cost-effective composite solutions that eliminate the need for chemical modifications. These findings are expected to advance efficient and sustainable HIPS-based composites, aligning with the growing demand for environmentally friendly materials.

## 2. MATERIALS AND METHOD

The materials used in this study are HIPS (TRINSEO STYRON 470) with a density of 1.03 g/cm$^3$ purchased from PT Focus Color Indonesia and OPEFB fiber procured from Polytech Indonesia. The OPEFB preparation, composite compounding process, specimen preparation, impact strength test, and thermal properties test were conducted at the Chemical Engineering Operations Laboratory and Polymer Laboratory at Polytechnic STMI Jakarta. Morphology testing using SEM was conducted at the Advanced Characterization Laboratory of the National Research and Innovation Agency (BRIN) in Banten, Indonesia.

### 2.1 Preparation of HIPS/OPEFB Composite Specimen Samples

The OPEFB was sieved and dried (100°C, 1 hour) to obtain dry OPEFB with a size of 100 mesh. The

**Table 1.** Variation of HIPS/OPEFB composite mass composition

| Variation of OPEFB (%w) | Component | | | | Total Weight |
|---|---|---|---|---|---|
| | HIPS | | OPEFB Fiber | | |
| 0 | 100% | 400 g | 0% | 0 g | 400 g |
| 10 | 90% | 360 g | 10% | 40 g | 400 g |
| 15 | 85% | 340 g | 15% | 60 g | 400 g |
| 20 | 80% | 320 g | 20% | 80 g | 400 g |

HIPS/OPEFB composite was prepared using a Teach-Line® Compounder ZK with the variations shown in Table 1. The dried composite was molded into composite sheets using a Manual Forming Machine (MFM) Comnetech QC-601A with the hot press method. The composite sheets were dried and cut using a grinder to prepare the specimen samples for impact strength test according to ISO 179-2 standard, with specimen dimensions of 8 cm in length, 1 cm in width, and 0.4 cm in thickness.

### 2.2 Impact Strength Test

The Impact strength test analyzes the strength, toughness, and ductility of a material when subjected to mechanical forces. In this study, the impact strength test was done using a Zwick Roell impact tester, using the Charpy unnotched method with ASTM D6110 and ISO 179-2 standards. Ten specimens will be used to test each weight percentage variation of OPEFB.

### 2.3 Morphology Test

The Scanning Electron Microscope (SEM) Hitachi SU350 was used to evaluate the surface morphology and homogeneity of OPEFB filler dispersion within the HIPS polymer matrix. The specimens tested are those with the highest and the lowest impact strength. In this study, three magnifications (200x, 500x, and 1000x) were used for morphology tests with SEM.

### 2.4 Thermal Properties Test

This research used the Differential Scanning Calorimetry (DSC) 214 Polyma, the thermal analysis instrument for measuring the difference in heat flow between a sample and a reference as a function of time or temperature. DSC was used on all variations of OPEFB percentage by conducting the first heating, cooling, and reheating phases. However, the analysis focuses on the data obtained from the cooling phase and the second heating phase. In this study, the DSC test was performed to find the glass transition temperature ($T_g$), the melting temperature ($T_m$), and the melting enthalpy ($\Delta H_m$). $T_m$ is the temperature as the polymer chains in the composite can move freely in the molten state and lack any ordered arrangements. The endothermic melting process requires adding heat, referred to as the melting enthalpy ($\Delta H_m$). The determination of $\Delta H_m$ comes from the area of a melting peak observed in the thermograph. If the sample is molten and cooled, it will reach $T_g$. In the thermograph, the temperature in the middle of the inclined region is taken as $T_g$.

## 3. RESULTS AND DISCUSSION

The data obtained from this research are used to determine the effect of OPEFB on the mechanical and thermal properties of HIPS/OPEFB composites. The average impact strength for ten specimens in each OPEFB weight percentage variation was calculated. Surface morphology was observed on composite for the samples with the highest and lowest impact strength, excluding pure HIPS, using SEM. Meanwhile, the thermal properties test will find the $T_g$, $T_m$, and $\Delta H_m$ for these composites.

### 3.1 The Analysis of OPEFB Influence on the Impact Strength of HIPS/OPEFB Composites

The impact strength represents the energy a material absorbs, reflecting its resistance ability to break under a sudden mechanical blow. Impact strength can be used to compare the toughness properties of one material with another. In this study, the impact strength of HIPS/OPEFB composites for each OPEFB variation is illustrated in Figure 1. The addition of OPEFB leads to a decrease in the impact strength of the HIPS/OPEFB composites. The fracture type for all specimens was a complete break. As shown in Figure 1, the highest impact strength is observed in the composite with 0% OPEFB addition, with a value of 12.06 kJ/m$^2$. Conversely, the lowest average impact strength in the HIPS composite, with the highest weight percentage in this study, is 20%, exhibiting an impact strength of 4.55 kJ/m$^2$.

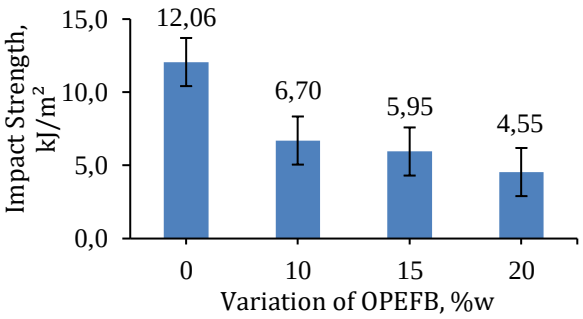


**Figure 1.** The Influence of OPEFB on the impact strength of HIPS/OPEFB Composites

The reduction in impact strength resulting from the addition of OPEFB filler is caused by the influence of interfacial bond strength and the properties of both the HIPS matrix and the OPEFB filler. Interfacial bond strength is the key factor influencing the overall mechanical properties of composites (Wang & Zhao, 2019). The interfacial bond strength between the matrix and the filler is crucial for efficient load transfer.

When the bond is strong, stress applied to the composite is effectively transferred from the matrix to the filler, which helps absorb and dissipate energy. A weak bond, on the other hand, leads to poor load transfer, causing premature failure and reduced impact strength. The interfacial bond strength in composite materials is intricately linked to the compatibility of the composite components, like the matrix and the filler. The compatibility affects how well these components interact at their interface, which in turn influences the overall performance of the composite. Previous studies have identified that poor compatibility between composite constituents is primarily due to differences in their hydrophilic and hydrophobic properties (Bachtiar et al., 2012). OPEFB are recognized for their hydrophilic properties due to their high cellulose content (Pramono et al., 2022). Cellulose is inherently hydrophilic due to the presence of hydroxyl (OH) groups that can form hydrogen bonds with water molecules (Wei et al., 2020). The two materials, which have different affinities for water, can hinder the adhesion processes needed for effective composite formation, leading to inadequate dispersion of fillers to the matrix and consequently decreasing the impact strength of HIPS/OPEFB composites.

The properties of both the matrix and the filler play a crucial role in the effectiveness of the interfacial bond. A hydrophilic natural compound like OPEFB may not bond well with a hydrophobic polymer matrix like HIPS because the differing affinities for water affect adhesion. The decrease in impact strength due to the addition of hydrophilic natural compounds has also been observed in previous studies (Bachtiar et al., 2012; Montoro et al., 2017; Vilaseca et al., 2004). Those previous studies observed that the decrease in impact strength is also caused by the restriction to matrix yielding imposed by those natural compounds. Yielding refers to the deformation of the matrix under stress before it undergoes failure or fracturing. As more OPEFB fillers are added to the HIPS matrix, the matrix material's movement and elastic deformation capability under stress can be restricted.

### 3.2 Morphology Analysis

In this study, morphology evaluation was conducted using SEM to examine the distribution of OPEFB fillers within the HIPS matrix. The 10%w and 20%w OPEFB samples exhibited the highest and lowest impact strength, excluding the 0%w OPEFB addition variation. Figure 2 shows that the voids generated in the 10%wt OPEFB variation are smaller and more uniformly distributed than the 20%wt OPEFB variation.

The variation in pore sizes and their distribution is critical as it influences the mechanical properties of the composites. The smaller and more uniform pores in the 10%wt OPEFB suggest that stress regions are not concentrated in a particular point. In contrast, adding 20 wt% OPEFB results in larger and irregularly distributed pores, likely leading to more significant stress concentrations and potentially creating weak points throughout the composite. This phenomenon can explain the reduction in impact strength, as the material becomes more prone to crack initiation and propagation under stress.

Adding a higher percentage of OPEFB can result in larger and unevenly distributed pores due to the hydrophilic nature of OPEFB. The stress on the surrounding HIPS matrix increases as more OPEFB fillers are added and swell due to moisture. This stress can cause the HIPS matrix to crack, leading to the formation of voids. Hydrophilic fillers can swell in the presence of moisture, creating voids and poor bonding and affecting the mechanical properties of the composite (Juliana et al., 2019). The incompatibility between the hydrophobic polymer matrix and hydrophilic additives often leads to void formation, as observed in previous studies where insufficient adhesion between the matrix and reinforcements was caused by their differing water affinities (Alfatah et al., 2022; Bakri et al., 2015). This aligns with previous research stating that water absorption is a critical factor affecting composite performance, as it typically results in poor adhesion between the matrix and fibers, ineffective stress transfer, matrix degradation, and dimensional instability (Balogun et al., 2020; Mrad et al., 2018; Ramlee et al., 2019).

When some synthetic fillers are used instead of hydrophilic natural fillers like OPEFB, the issues related to moisture absorption and swelling are significantly reduced or eliminated. Some synthetic fillers are generally hydrophobic or have low moisture affinity (Gurmu et al., 2024). Several synthetic fillers typically don't swell or absorb moisture, which minimizes the risk of void formation. In contrast, natural fillers like OPEFB absorb water due to their hydrophilic components (e.g., cellulose and hemicellulose), causing swelling that creates stress on the matrix and results in cracks and voids. While synthetic fillers provide better compatibility with matrix, their production and disposal often have a higher environmental impact than natural fillers (Bledzki & Gassan, 1999). Despite their compatibility challenges, natural fillers are more sustainable and biodegradable than synthetic fillers (Rama Rao & Ramakrishna, 2022).

### 3.3 Thermal Properties Analysis

We have recorded the DSC test result for each sample variation of OPEFB weight percentage, as shown in Table 2. The presented data shows that adding OPEFB filler to the HIPS polymer significantly impacts its thermal properties, specifically $T_g$, $T_m$, and $\Delta H_m$. The temperature at which the material undergoes a phase change from a glassy state to a rubbery state as the temperature increases is called $T_g$. When the temperature drops below $T_g$, the mechanical properties of the composite change from elastic to brittle due to the restriction of polymer chain mobility. If the heat is continuously added above Tg, the polymer chains in this composite can move around freely as the temperature reaches $T_m$.

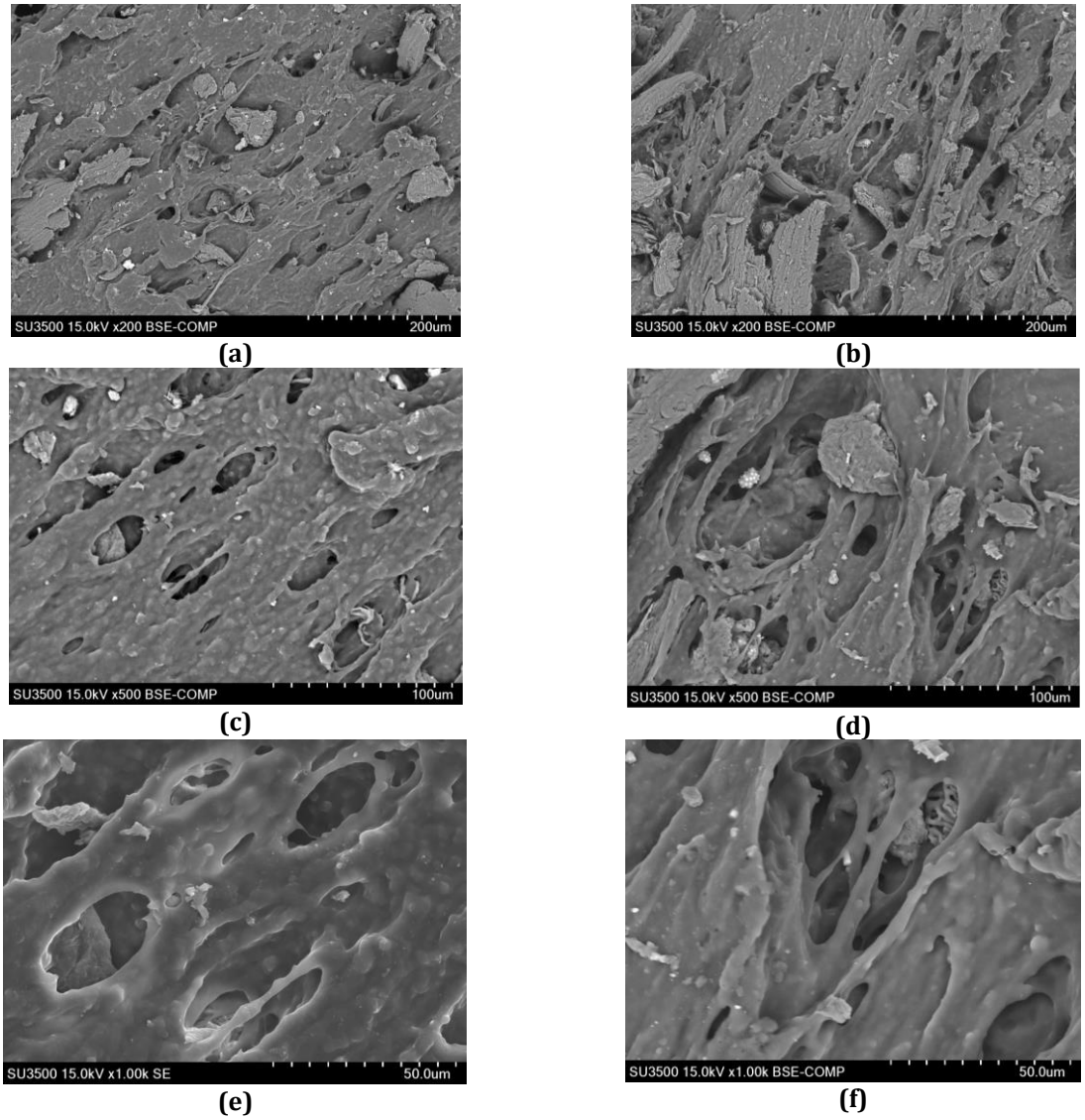


**Figure 2.** Surface morphology of samples with different OPEFB fiber percentage and magnifications (a) 10%w at 200x magnification, (b) 30%w at 200x magnification, (c) 10%w at 500x magnification, (d) 30%w at 500x magnification, (e) 10%w at 1000x magnification, (f) 30%w at 1000x magnification.

**Table 2.** Thermograph data for each weight percentage of OPEFB

| OPEFB (%w) | $T_g$ (°C) | $T_m$ (°C) | $\Delta H_m$ (J/g) |
|---|---|---|---|
| 0 | 114,6 | 161,8 | 21,33 |
| 10 | 108,9 | 164,6 | 13,87 |
| 15 | 108,4 | 154,7 | 14,06 |
| 20 | 109,9 | 145,2 | 12,34 |

The data show that $T_g$ decreases when OPEFB is added to HIPS. The subtle changes in HIPS polymer structure can lead to significant changes in $T_g$. This decrease may indicate interactions between the OPEFB filler and the HIPS polymer matrix, affecting the polymer chain's ability to move at lower temperatures. The trend observed from 0% to 20% OPEFB shows a general decrease in $T_g$, with slight fluctuations, possibly due to the increased weight of hydrophilic materials disrupting the HIPS polymer structure. The hydrophilic material in OPEFB, such as cellulose, hemicellulose, and lignin, disrupts the polymer matrix by absorbing moisture and leading to a plasticizing effect, which further reduces the $T_g$ (Shinoj & Visvanathan, 2014). The presence of voids caused by hydrophilic fillers within a hydrophobic matrix also enhances chain mobility at lower temperatures, reducing the $T_g$ value.

The heterogeneous composition of lignocellulosic biomass in OPEFB significantly influences its interaction with polymer matrix, particularly in hydrophobic polymers like HIPS. The dominant compounds in OPEFB that disrupt the polymer matrix include cellulose, hemicellulose, and lignin, each contributing uniquely to the matrix disruption due to their intrinsic properties. The primary challenge in utilizing natural fillers lies in the significant variability of their properties and characteristics. Natural fibers are generally valued for their low energy requirements, lightweight nature, non-abrasiveness, affordability, renewability, biodegradability, ease of access, and global availability. However, environmental factors such as sunlight, rainfall, soil quality, the water intake of palm oil plants during growth, and variations in

processing and production conditions can influence the properties of natural fillers (Gholampour & Ozbakkaloglu, 2020). Consequently, the composition and characteristics of OPEFB filler may vary between harvesting seasons and even within the same cultivation area. The chemical composition of OPEFB is cellulose, hemicellulose, lignin, ash, water, benzene, and pentosan, with percentage variations influenced by factors such as plant growth conditions, extraction processes, and treatment methods (Rama Rao & Ramakrishna, 2022).

The addition of OPEFB makes more amorphous regions into the HIPS matrix, reducing the overall crystallinity of the composite, which typically results in a lower $T_g$. The variations at different OPEFB percentages, with a slight increase at 20% compared to 15%, might be due to the differing interactions of cellulose, hemicellulose, and lignin with the matrix. The major components of OPEFB are cellulose (40–50%), hemicellulose (20–30%), and lignin (15–20%) (Ahmad et al., 2019; Akhlisah et al., 2021). The amorphous and crystallinity structure in cellulose, hemicellulose, and lignin can influence the $T_g$ of HIPS/OPEFB composites with OPEFB variations of 10%wt, 15%wt, and 20%wt. Polymers with a higher proportion of amorphous regions typically exhibit a lower $T_g$, whereas those with greater crystallinity generally have a higher $T_g$.

Even though the cellulose structure is rigid and highly crystalline (Arakawa & DeForest, 2017), cellulose might not blend smoothly into the HIPS matrix. Cellulose in OPEFB filler potentially disrupts the polymer chain alignment and improves the mobility of the polymer chains due to hydrophilic properties impacting the $T_g$. Meanwhile, Hemicellulose is amorphous and less organized than cellulose (Brunner, 2014). Its amorphous nature and shorter chain length compared to cellulose could slightly decrease the $T_g$ of the composite. Hemicellulose can also form hydrogen bonds with water molecules and absorb moisture into the composite (Md Noh & Wusko, 2020). Those hydrophilic compounds might plasticize the HIPS matrix, lowering the $T_g$. Lignin is a highly amorphous polymer that can act as a natural binder (Chen & Chen, 2014). In composites, lignin can contribute to the stiffness and stability of the structure (Serra-Parareda et al., 2020; Yudha et al., 2023). Lignin can potentially increase the $T_g$ if it enhances the cross-linking within the matrix.

Meanwhile, $\Delta H_m$ represents the heat required to melt the crystalline regions of a polymer. The higher $\Delta H_m$ indicates a great amount of crystalline structure in the material because more energy is required to break down the orderly crystal structures within the polymer matrix. Crystallinity refers to the structure in which the polymer chains are orderly packed in a regular, lattice-like structure. Meanwhile, $T_m$ is the temperature at which the polymer melts. $T_m$ slightly increases with 10% OPEFB but decreases as the OPEFB content increases. OPEFB fillers, being more amorphous and irregular in shape than HIPS, disrupt the regular crystalline structure of the HIPS matrix. As more OPEFB is added, it becomes increasingly difficult for the HIPS/OPEFB composite to achieve a highly ordered crystalline structure. Incorporating different components in OPEFB, which may contain components like lignin and hemicellulose, acts as an impurity within the HIPS matrix. These materials, with various compositions, can interfere with the polymer chain alignment and the regular packing needed for crystallization, thus increasing or decreasing the $T_m$.

In previous discussions, the difference in water affinity between HIPS and OPEFB was noted to potentially weaken the interfacial bonds between the matrix and the filler. Suppose the interface between the OPEFB filler and the HIPS matrix is weak or poorly bonded. In that case, it can cause the polymer chains to be less tightly packed or aligned, reducing the material's crystallinity and consequently lowering its melting temperature ($T_m$). In conclusion, DSC test results indicate that adding OPEFB to HIPS significantly impacts its thermal properties of $T_g$, $T_m$, and $\Delta H_m$. The addition of OPEFB causes variability in crystallinity due to its structured order and the hydrophilic nature of components like cellulose, hemicellulose, and lignin, which disrupt the polymer matrix and enhance chain mobility. Moreover, while initial additions of OPEFB slightly increase $T_m$, further increases lead to a decrease, underscoring the complex interactions between the filler and the HIPS matrix, which could be affected by the heterogeneous composition of lignocellulose.

The dominant compounds disrupting polymer matrices are cellulose and hemicellulose due to their hydrophilic properties and moisture absorption, which induce swelling, weaken interfacial bonding, and reduce structural integrity. Lignin, while contributing to stiffness, also disrupts the uniformity of the matrix due to its amorphous structure. Understanding the role of these components is critical for optimizing the use of OPEFB as a filler in polymer composites and addressing compatibility challenges.

## 4. CONCLUSION

This study investigates the effects of integrating OPEFB filler into the HIPS matrix as composites, focusing mainly on how OPEFB influences mechanical and thermal properties. The addition of OPEFB decreases the impact strength caused by the weakened interfacial bonds between the hydrophilic OPEFB filler and the hydrophobic HIPS matrix. This disparity leads to a lack of compatibility in the composite structure, adversely affecting its mechanical integrity. The morphology analysis confirms these findings, indicating that with increasing OPEFB content, both pore size and the uneven distribution of voids become more pronounced and correlate with the mechanical properties of the composites.

Thermal analysis revealed that the further addition of OPEFB also generally led to reductions in both the glass transition temperature ($T_g$) and the melting temperature ($T_m$) of the composites. These changes indicate the increased amorphous regions within the composite. The thermal properties of HIPS are also altered by the addition of OPEFB due to the disruption

caused by its hydrophilic components—cellulose, hemicellulose, and lignin—in the polymer matrix. These lignocellulose components, by interacting with moisture, further act as plasticizers, decreasing the $T_g$ and affecting the overall thermal properties of the composites.

The study concludes that while OPEFB offers benefits like availability and sustainability as a natural filler, the challenge lies in optimizing the interfacial compatibility between OPEFB and HIPS to enhance the composite's performance. Addressing this challenge is crucial for fully harnessing the potential of OPEFB in improving the properties of HIPS composites, suggesting a significant opportunity for further research and development in composite material technology.

## 5. ACKNOWLEDGMENT

We gratefully acknowledge the support of Polytechnic STMI Jakarta for providing financial assistance and equipment for this research.

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