Advancements in Oil Palm-Derived Composites: Engineering Insights and Innovation

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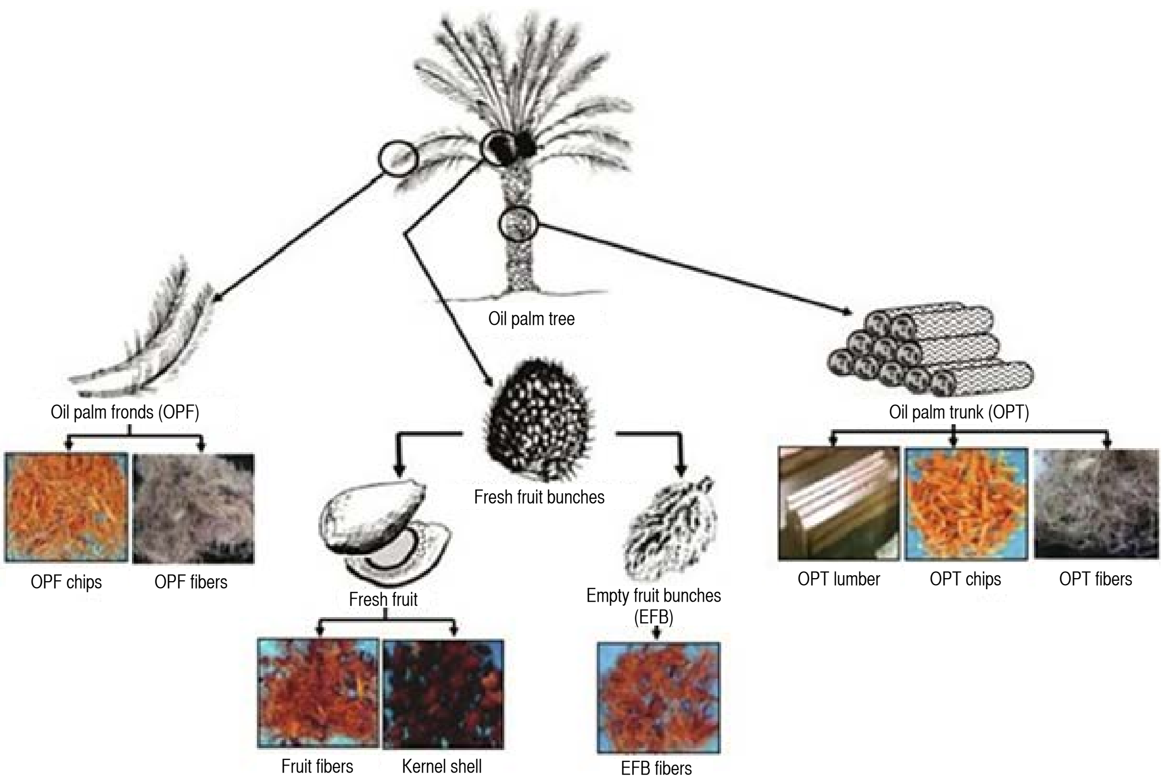
INTRODUCTION

The palm oil industry stands as the primary contributor to biomass in Malaysia, generating a substantial amount of oil palm biomass waste annually. The industry produces a significant volume of biomass each year, comprising oil palm fronds (OPF), empty fruit bunches (EFB), oil palm trunks (OPT), palm mesocarp fibres, and palm kernel shells (PKS), as illustrated in *Figure 1*. The oil palm biomass is being effectively transformed into value-added products through various industrial processes and applications (Ilyas *et al.,* 2022). The abundance of these biomass can be turned into highly valuable composite products, which will bring in additional revenues for the nation. Therefore, much research on the replacement of man-made fibres with oil palm fibres as reinforcement materials in polymer composites has been invested for a more sustainable palm oil circular economy. Oil palm-derived composites may prove to be one of the most auspicious green materials owing to its acceptable mechanical properties, abundance, renewability, and biodegradability.



Source: Dungani *et al.,* 2018.

Figure 1. Types of oil palm biomass from the palm oil industry.

OIL PALM-DERIVED COMPOSITES

A bio-composite refers to a material comprising two or more distinct components, with one of these components sourced from renewable biological resources. Typically, these materials incorporate natural fibres, such as those derived from plants like oil palm fibres, which are intricately embedded within a matrix of synthetic or polymer materials. In the context of oil palm-derived composites, the biomass generated by the palm oil industry serves as the natural and renewable component, while the matrix is commonly composed of synthetic or bio-based polymers. This combination results in a composite material that not only benefits from the sustainability of the bio-component derived from oil palm but also harnesses the versatile properties of synthetic or bio-based polymers, thus offering potential ecological and resource-efficiency advantages. Generally, the oil palm-derived composites can be categorised based on the specific components derived from the oil palm tree, including:

1. Oil palm trunk (OPT)-based composite.

   Oil palm veneer is a product obtained from OPT by peeling or slicing them into thin veneers. It serves as a decorative or composite-facing material. Laminated veneer lumber (LVL), derived from veneer, is an engineered wood product formed by laminating thin wood veneers, aligning the grain of all layers parallel to the length of the LVL beam or board. In contrast, plywood is created by bonding multiple layers of thin wood veneers, with the grain direction of adjacent layers perpendicular to each other, enhancing the strength and stability of the material through cross-grain construction.

2. Oil palm frond (OPF)-based composite.

   Composites derived from OPF can be categorised into two main types based on their forms: OPF particle and OPF fibre composites. The OPF particle composite uses particles or finely chopped fragments, while the OPF fibre composite utilises the longer and finer fibres as reinforcing materials within a matrix.

3. Empty fruit bunch (EFB)-based composite.

   The EFB has a wide range of uses in composite products, demonstrating its adaptability to a variety of categories. EFB particles are used as a key component in the production of particleboard, contributing to its structure and properties. In the form of fibres, EFB are incorporated into the manufacturing of fibreboard to enhance its properties, contributing to a more sustainable composition. Also, EFB fibres are utilised to create bindless boards, which do not require conventional adhesives in their production. EFB fibres may be employed in the production of insulation materials and sound absorption panels, enhancing thermal and acoustic properties. EFB fibres can also incorporated into cement boards to improve their mechanical properties and reduce weight.

4. Hybrid composites.

   The hybridisation in oil palm-derived composites can be tailored to achieve a balance of strength, flexibility, durability, and other desired attributes. This approach allows for customisation to meet the requirements of specific applications. Oil palm hybrid composites can be created by combining oil palm-based sources with other natural fibres like kenaf, bamboo, jute, and flax. This blending of materials enhances the versatility and performance of the composite, allowing for a synergistic utilisation of properties from various renewable sources.

ENGINEERING INSIGHTS INTO OIL PALM-DERIVED COMPOSITES

Engineering insights into oil palm-derived composites involve a multidisciplinary exploration of the structural, mechanical, and processing aspects of materials derived from the oil palm tree. These oil palm-derived composites provide a sustainable alternative with the potential to revolutionise industries. To produce high-performance materials, researchers attempt to optimise the production processes and take advantage of the plentiful oil palm biomass waste. Researchers traverse the difficulties of making sure these composites fulfil the essential mechanical criteria for a variety of applications, from the difficult design of composite structures to the selection of matrix materials. Further investigation is being conducted into the integration of components produced from oil palm into hybrid composites. Here, the potential synergies with other natural fibres or polymers are being examined to develop creative solutions that strike a balance between strength, flexibility, and environmental sustainability (Khalil *et al.,* 2012). With the advancement of research, these technical insights open new avenues for sustainability and environmental friendliness, demonstrating the potential applications of composites made from oil palm in a variety of industries, such as automotive and construction.

Researchers are also taking the lead in tackling issues with durability and processing methods, and integrating these components into current industrial procedures in the field of oil palm-derived composites. Researchers can ensure the functionality and lifespan of oil palm composites in practical applications by understanding how the materials behave under various conditions using rigorous testing and experimentation. The cooperation between materials scientists, structural engineers, and industry professionals enhances a comprehensive understanding of the potential and limitations of composites made from oil palm. This all-encompassing strategy supports the creation of sustainable materials and is in line with the larger objectives of the palm oil sector to establish a circular economy. In the end, technical knowledge of composites made from oil palm is essential to the advancement of materials science and sustainable manufacturing, promoting innovation towards eco-friendly solutions.

INNOVATIONS IN OIL PALM-DERIVED COMPOSITES

Oil palm-derived composites have potential uses in structural and non-structural applications, such as automotive, construction, panel, furniture, and household products. Various applications from different parts of oil palm biomass are listed in *Table 1.*

Aligned with its objectives, the Malaysian Palm Oil Board (MPOB) has successfully achieved the commercialisation of several oil palm-derived composites, marking a significant milestone in advancing sustainable practices and innovation. By harnessing the versatile properties of oil palm-based materials, MPOB is contributing to the development of eco-friendly alternatives in many sectors. This initiative not only promotes the efficient utilisation of palm oil resources but also emphasises MPOB's commitment to environmentally conscious practices, paving the way for a more sustainable and resilient future for various industries globally. Some of the commercial products include:

TABLE 1. APPLICATIONS OF OIL PALM-DERIVED COMPOSITES

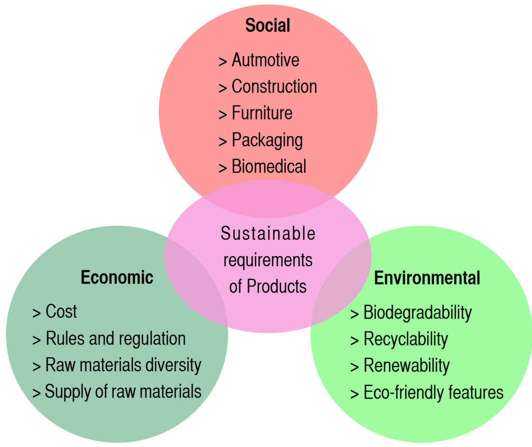
Oil palm biomass	Applications	References
Oil palm trunk	Veneer	Saari *et al.* (2020).
	Plywood	Abdul Khalil *et al.* (2010); Hoong *et al.* (2012).
	LVL	Hashim *et al,* (2011); Sulastiningsih *et al.* (2020).
	Particleboard	Ahmad *et al.* (2011).
	Paper production	Phruksaphithak and Wangprayot (2020).
	Geopolymer Concrete	Malkawi *et al.* (2020).
	Plywood	Nuryawan *et al.* (2020).
	Furniture	Suhaily *et al.* (2019).
Oil palm frond	Sound absorption board	Sihabut and Laemsak (2008).
	Composite board	Rasat *et al.* (2011).
	Polymer composite	Abdul Khalil *et al.* (2007).
	Hybrid particleboard	Wahida and Najmuldeen (2015).
Empty fruit bunch	Medium density fibreboard (MDF)	Ramli *et al.* (2002); Izani *et al.* (2012); Izani *et al.* (2013); Azman *et al.* (2015) and Ibrahim *et al.* (2016).
	Hybrid MDF	Khalil *et al.* (2010); Ibrahim *et al.* (2014); Karim *et al.* (2020) and Hanan *et al.* (2018).
	Polymer composite	Saputra *et al.* (2016) and Arif *et al.* (2017).
	Packaging material	Ayu *et al.* (2020).
	Bumper fascias	Hassan *et al.* (2018).
	Laterite brick	Ismail and Yaacob (2011).
	Thermal insulation board	Ramlee *et al.* (2021).

1. Commercialisation of MDF from oil palm trunk (MPOB/ Dongwha Fibreboard collaboration)
2. Mobile palm peeler for veneer and palm plywood production (MPOB/ Nexfuel Sdn. Bhd collaboration)
3. Commercialisation of oil palm fibres for car components (MPOB/Carpet International Malaysia collaboration)
4. Snipper press machine to produce short length and semi-dried fibres (MPOB/Hur Far Engineering Works Sdn. Bhd. collaboration)

SUSTAINABILITY OF OIL PALM-DERIVED COMPOSITES

Oil palm-derived composites are considered one of the emerging green materials of the present time due to their biodegradability, recyclability, and sustainability, which can have a significant effect on the future climate. The sustainability of oil palm-derived composites is grounded in the ability of these materials to provide environmentally responsible solutions while addressing the challenges of resource depletion and ecological impact. By utilising oil palm derivative sources in the development of composites, industries can reduce their reliance on non-renewable resources, thereby lowering their carbon footprint (Farid *et al.,* 2019). Additionally, the bio-composites have lower environmental impacts than synthetic fibre reinforced composites.

Moreover, the sustainability of oil palm-derived composites extends beyond their raw material origins. These composites can contribute to circular economy practices by being designed for recyclability or biodegradability, minimising end-of-life environmental impact. Furthermore, innovations in the production processes, such as eco-friendly manufacturing, and palm-based binder and filler can reduce energy consumption and enhance the overall sustainability profile of oil palm-derived composites. As industries increasingly prioritise sustainability, these composites emerge as a viable and responsible choice, offering a pathway towards greener and more sustainable practices across various sectors. *Figure 2* illustrates different parameters associated with sustainable products.



Source: Khalid *et al.,* 2021.

Figure 2. Several factors related to sustainability.

FUTURE PERSPECTIVE

The use of oil palm-derived composites in engineering applications is justified owing to their comparable properties and lower environmental effects. But there are huge challenges involved in controlling and improving the mechanical properties of oil palm-derived composites. Further exploration is also required from the research community to support and encourage the utilisation of these composites as well as novel chemical techniques in the advancement of oil palm-based composites. The development of oil palm-derived composites is quickly expanding and is envisaged as a future sustainable material for emerging applications.

With the significant progress in green materials, it is assumed that in the future these advancements will lead to improved properties of oil palm-derived composites, particularly for new applications. Through the methodical integration of several aspects in the development of oil palm reinforcing materials, researchers have achieved significant progress. These parameters encompass careful considerations involving size, chemical modification, additive integration strategy, synergistic incorporation with other biomass sources, and nanostructure incorporation, all of which are intended to expand their profound effects on the composite properties. Most of these efforts have been successful in improving the quality of oil palm-derived composites for possible uses.

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