THE FUSED DEPOSITION MODELING OF POFA REINFORCED COMPOSITE POLYMER

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For my beloved parents, my family and my best friends, thank you for everything especially for their support and everlasting love. To my supervisor and research mates, thank you for any help and cooperation during my toughest moment and being such an understanding person.

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ABSTRACT

Palm oil fuel ash (POFA) is one of the waste products in the palm oil industry, whereas the abundance of that waste largely contributed to environmental effects. A strong interest in the development of renewable products to reduce the environmental effects has been focusing on the use of waste source as reinforcements in polymer matrix composites. In 3D Printing Fused Deposition Modeling (FDM), composite filament material has started to be used in the pattern development application. However, in FDM pattern development, the composite filament has a common issue especially in reference to the nozzle clogging problem that relates to the critical process in composition mixing and filament preparation. Therefore, this research aims to investigate the capability of different percentage composition in the range of 20vol% - 60vol% of POFA with polypropylene (PP) materials formed into solid composite filament for FDM machine. The composite materials were mixed homogeneously using the Brabender mixer machine and the addition of 5vol% and 8vol% maleic anhydride grafted polypropylene (MAPP) as a compatibilizer to improve the bonding ability of the PP matrix and POFA as well as to improve flowability during the next process. The Melt Flow Index (MFI) test was conducted on POFA+PP+MAPP compositions to investigate the data of viscosity which is important for the filament extrusion process. The single screw extrusion machine was used in the fabrication of composite filaments with a diameter and length range of 1.70 ± 0.02mm and 60 to 70cm respectively. Then, the filaments were run for deposition test on the FDM machine by printing the ISO527-1 (dog bone sample). Finally, the properties in terms of mechanical and surface observation were investigated for the successful printed sample. The investigation results of the POFA filament deposition test on FDM shows that 40vol% POFA, 55vol% PP, and 5vol% MAPP gave the highest tensile strength which is 27.40MPa compared to other composition and virgin PP, 20% net increment of elongation at break compared to 20%vol POFA, lower warping defect and high initial degradation temperature with 318ºC.

ABSTRAK

Abu bahan bakar minyak sawit (POFA) merupakan salah satu produk sisa dalam industri kelapa sawit, di mana lambakan sisa tersebut memberi kesan besar terhadap alam sekitar. Dalam Permodelan Pengendapan Lakur 3D (FDM), penggunaan filamen berunsurkan bahan komposit mula digunakan dalam aplikasi pembinaan produk. Walau bagaimanapun, dalam pembuatan produk menggunakan FDM, filamen komposit mempunyai masalah umum terutamanya mengenai masalah penyumbatan pada muncung pengeluaran, di mana faktor utama yang berkaitan dengan permasalahan itu adalah proses kritikal semasa pencampuran komposisi dan penyediaan filamen. Oleh itu, penyelidikan ini bertujuan untuk mengkaji keupayaan komposisi peratusan yang berbeza dalam lingkungan 20vol% - 60vol% POFA dengan bahan polipropilena (PP) telah dibentuk menjadi filamen komposit padat bagi digunakan di mesin FDM. Proses campuran bahan komposit itu diadun sebati dengan menggunakan mesin pengadun Brabender dan ditambahkan dengan 5vol% dan 8vol% maleic anhydride polypropylene (MAPP) sebagai alat penyesuaian untuk meningkatkan keupayaan ikatan matriks PP dan POFA serta memudahkan proses pengaliran semasa proses seterusnya. Ujian Melt Flow Index (MFI) dilakukan ke atas semua komposisi POFA+PP+MAPP untuk menyiasat data kelikatan yang penting untuk proses penyemperitan filamen. Mesin penyemperitan skru tunggal digunakan untuk membentuk filamen komposit dengan diameter dan panjang masing-masing iaitu 1.70 ± 0.02 mm dan 60 hingga 70cm. Kemudian, filamen dijalankan untuk ujian pemendapan pada mesin FDM dengan mencetak ISO527-1 (sampel tulang anjing). Akhirnya, sifat dari segi pemerhatian mekanikal dan permukaan disiasat untuk sampel bercetak yang berjaya. Hasil penyiasatan ujian pemendapan filamen POFA pada FDM menunjukkan bahawa 40vol% POFA, 55vol% PP, dan 5vol% MAPP memberikan kekuatan tegangan tertinggi iaitu 27.40MPa berbanding komposisi lain dan PP dara, kenaikan bersih pemanjangan 20% pada waktu rehat berbanding dengan POFA 20% vol, kecacatan melengkung yang lebih rendah dan suhu penurunan awal yang tinggi iaitu dengan 318ºC.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
FDM	-	Fused Deposition Modeling
MAPP	-	Maleic Anhydride Polypropylene
MFI	-	Melt Flow Index
POFA	-	Palm Oil Fly Ash
PP	-	Polypropylene
RP	-	Rapid Prototyping
SEM	-	Scanning Electron Microscope
TGA	-	Thermogravimetric Analysis

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This research is generally about the composite filament for Fused Deposition Modeling (FDM) application. The composite filament consists of the main matrix, filler and compatibilizer agent which acted as an additive material to improve the bonding between them. In this chapter, the introduction of this research was explained generally. Firstly, the explanation was given on the background of the research. Then, the issues and objectives of the research were critically highlighted in this chapter. Lastly, the scope of the study was defined to outline the research limitations and the expected results were discussed as predicted outcomes for this research.

1.1 Research Background

Natural fibre composites (NFCs) are alternatively referred as the bio-composites which gained much awareness due to their numerous advantages in a variety of applications and appliances (Khan *et al*., 2012). Composite materials consist of two or more elements of matrix materials and reinforcement materials. In NFCs, they are usually made from a combination of plastics and fibres, whereas plastics as a matrix and natural fibres as the reinforcement. However, before the applications of NFCs are being commercialised, it is necessary to utilise the true advantage of material properties and gain a general understanding of the challenges involved in implementing them, particularly on the processability (Pandey *et al*., 2015).

Malaysia is actively involved in the oil palm plantation industry which is also known as the world's largest palm oil producer and exporter due to millions hectares of land was dedicated in oil palm cultivation (Ng *et al*., 2019). Moreover, a statistic reported by Malaysian Palm Oil Board (MPOB) in 2018 as shown in Table 1.1

proves that the total area of matured and immatured oil palm trees planted in Malaysia was 5849330 hectares (ha) in 2017. This country is capable to provide a million tonnes of palm oil and palm kernel oil. Palm oil is derived from the flesh of the fruit, while palm kernel oil is derived from the seeds or kernels (Sobuz *et al*., 2019).

Table 1.1: Statistical area (ha) of Oil Palm Planted 2017 (MPOB, 2018)

STATE	MATURED	%	IMMATURED	%	TOTAL	%
JOHOR	680,562	91.0	67,000	9.0	747,562	12.8
KEDAH	82,287	91.1	8,007	8.9	90,294	1.5
KELANTAN	121,085	77.9	34,287	22.1	155,372	2.7
MELAKA	51,237	90.2	5,574	9.8	56,811	1.0
NEGERI SEMBILAN	167,026	89.1	20,425	10.9	187,451	3.2
PAHANG	653,535	86.4	102,614	13.6	756,149	12.9
PERAK	364,090	88.1	49,221	11.9	413,311	7.1
PERLIS	641	94.1	40	5.9	681	0.0
PULAU PINANG	14,042	95.5	660	4.5	14,702	0.3
SELANGOR	123,139	90.3	13,222	9.7	136,361	2.3
TERENGGANU	149,519	88.5	19,395	11.5	168,914	2.9
PENINSULAR MALAYSIA	**2,407,163**	**88.3**	**320,445**	**11.7**	**2,727,608**	**46.6**
SABAH	1,378,655	89.0	170,590	11.0	1,549,245	26.5
SARAWAK	1,403,526	89.3	168,951	10.7	1,572,477	26.9
SABAH & SARAWAK	**2,782,181**	**89.1**	**339,541**	**10.9**	**3,121,722**	**53.4**
MALAYSIA	**5,189,344**	**88.7**	**659,986**	**11.3**	**5,849,330**	**100.0**

However, from the production, a huge amount of wastes over 100 million tonnes of biomass were generated from the milling process in the forms of fibres, nutshells, and empty fruit bunches (Fahmi *et al*., 2015). Scientific Malaysian Magazine (2017) also reported that without introducing modern methods of planting, harvesting, processing, and land management into mainstream operations, the palm oil mills in Malaysia contribute 80,000 metric tonnes of dry biomass annually and it keep rising in the coming years as the increasing of projected palm oil plantations and mills. Figure 1.1 shows the process involved in the palm oil industry and how the biomass is reused productively.

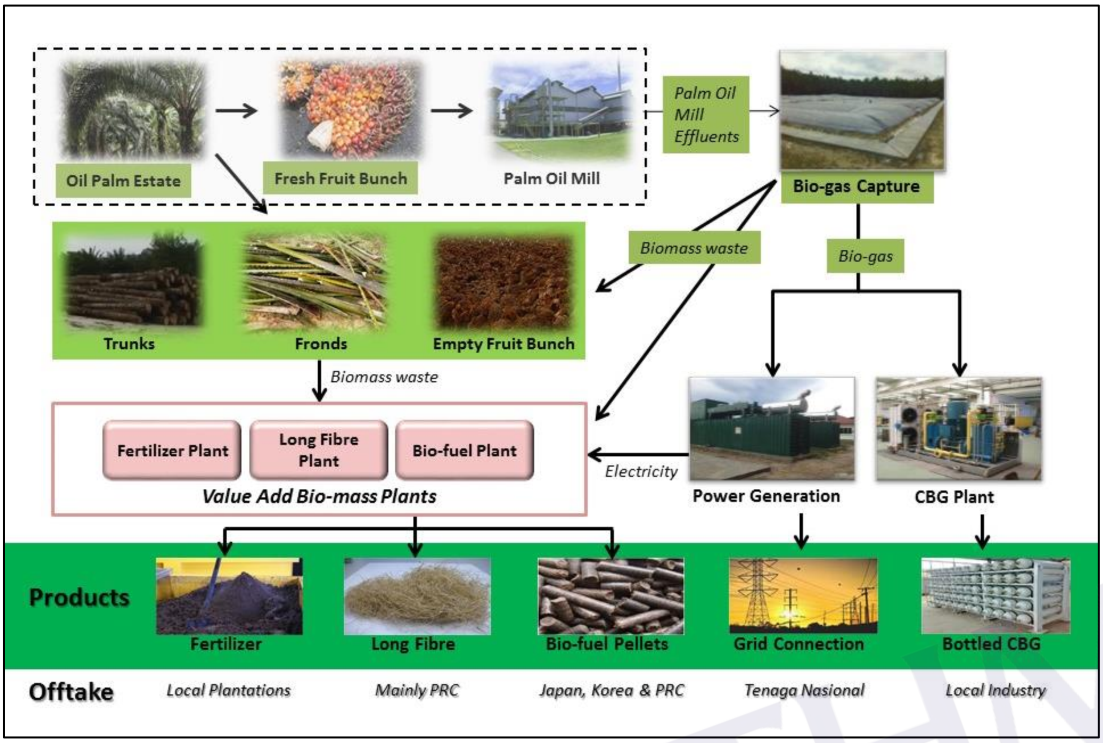

Figure 1.1: The process of oil palm industry (Scientific Malaysian Magazine 2017)

Palm oil fuel ash (POFA) is a source of silicate which the end products of oil palm bunches and kernels burning process at 800 to 1000℃ that used as a fuel to generate electricity (Cheng *et al*., 2019). The production process of POFA from palm oil processing is shown in Figure 1.2. Combustion in a steam boiler produces approximately 5% of POFA, whereas Malaysia is estimated to produce 3.14 million tonnes of POFA annually. It is also expected to grow annually in line with the increasing production of palm oil (Garba *et al*., 2019). The major disposal problem occurs due to the presence of these oil palm waste that badly affecting the environment. These wastes are typically disposed of in landfills. Nevertheless, they may cause environmental and health risks because as the wind passes through the landfill, they could be harmful to breathe (Wei *et al*., 2019). However, due to its major potential as supplementary cementing materials (SCMs) in the building industry, previous researchers attempted to use POFA as the secondary cementitious or pozzolanic materials to minimise the unhygienic disposal of POFA (Garba *et al*., 2019).

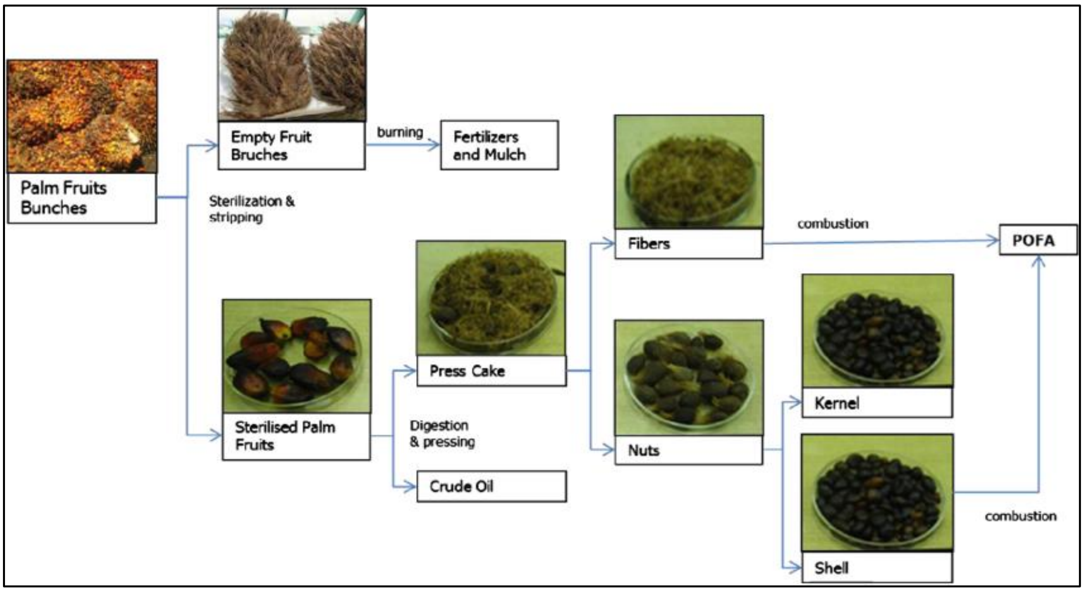

Figure 1.2: The schematic diagram for POFA production (Nagaratnam *et al*., 2016)

Lately in Malaysia, biomass source has been announced as an important issue that gives profit for the country. According to environmental concerns, the natural source becomes one of the interesting and fascinating materials in the industrial application that should be explored by engineers and researchers (Reza *et al*., 2013). Khalid *et al*. (2019) reported that based on consideration of the environmental issue and sustainable development in the modern production of polymeric materials, the modification of waste materials has also become an interesting research topic. This is a good opportunity for the industry to enhance the technologies from biomaterial as a new innovative product (Palm *et al*., 2015). Therefore, the reuse of POFA from landfill sites in the composite material application is a successful way to minimise environmental and health impacts and at the same time to support the efficiency of using composite materials.

Currently, in FDM application many researchers addressed the potential of polypropylene (PP) as a candidate for filaments in FDM process due to their widely available and interesting characteristics for industrialists such as reasonable price, nontoxic polymer with good recyclability, lightness, resistance to chemicals and good electrical insulation (Carneiro *et al*., 2015). In addition, the PP material was suitable to be used in some industrials such as food packaging, automotive, textile, construction, piping and medical facilities (Sodeifian *et al*., 2019). However, due to the crystalline nature and tendency toward warping PP not always suitable or remains quite rare in the 3D printing market (Spoerk *et al*., 2018). Therefore, Silva *et al*. (2017) was evaluated the potential solution to prevent printed parts of PP material from shrinking and warping by incorporate fillers such as short glass fibres into the polymer. In addition, in other research also, to improve the mechanical and thermal performance of PP material as the requirements demanded by engineering applications, PP was usually modified with additives and particles as a reinforced material (Costantino *et al*., 2019). Then, the fibre-reinforced thermoplastic matrix composites showed the commercial success in many application where various fibres are widely used as reinforcement polypropylene (PP) matrix to prepare the composites (Shubra *et al*., 2011).

Pandey (2015) revealed that the mixture of natural fibre with various polymers as a polymer composite filament obtained from the extrusion process has shown the potential of 3D printing to develop new products. Milosevic *et al*. (2017) reported that both strength and stiffness increase with natural fiber content when harakeke and hemp fiber filled in PP as composite filamnet. Then, Hui *et al*. (2011) has been successfully produced the FDM filament by mixing 30% 100-mesh wood flour, 60% HDPE, 6% maleic anhydride polypropylene (MAPP), and 3% stearic lubricant. The mechanical properties of composite materials made from maleic anhydride-grafted polyhydroxyalkanoate (PHA-g-MA) and coupling agent treated palm fibre (TPF) showed an improvement in tensile strength and interfacial adhesion, hence successfully fabricated as FDM filaments (Wu *et al*., 2017). Besides, the study by Lek (2016) showed the capability of 10% 0.1mm Oil Palm Frond (OPF) fibre mixed with HDPE to be used as composite filament in 3D printing. However, some improvements in the interaction between fibre and polymer are required due to poor interfacial derived from the hydrophobic nature of the fibre.

As stated in previous reports, there were numerous attempts on blending the biomass materials with a polymer to perform a composite material. However, there is a lack of research in making composite filament for FDM 3D printing using oil palm biomass.

The purpose of this study is to produce the composite filament with POFA filled by a single extrusion machine in PP polymer and deposited by FDM machines via layered production processes. The mixing ratio of the constituent material for POFA+PP+MAPP is investigated for optimal composition. Then, an effective compatibilizing agent material has been introduced to be used in the process of mixing the composite filament as a medium to improve the melt flowability in wire filament form. Therefore, to achieve a homogeneous mixing, wire filament manufacturing must adopt the compounding technique, methods, mixing ratio and time to ensure a constant diameter of approximately 1.75mm ± 0.2mm in standard filament sizing for this FDM unit.

1.2 Problem statement

Green environmental awareness has attracted researchers and industries to use biomass as an alternative primary filler for polymer bio-composites which can decrease the percentage of synthetic thermoplastics usage in the fabrication of products and help in reduced the environmental impact due to the overloading biomass waste in the land (Mazzanti *et al*., 2019).

Malaysia has held the title as one of the most productive palm oil producers in the world. POFA is one of the abundant waste materials and it was estimated that 3 million tons per annum of fly ash were produced in (Razi *et al*., 2016). Most of the abundance of fly ash especially in Malaysia is underutilized whereas this POFA have higher potential to be used in developing a polymer composite as a filler material (Elammaran *et al*., 2020).

Lately, bio-polymer is one of the hot topics among researchers as a sustainable material in the industry based on its mission to achieve sustainable development goals. Among the emerging technologies of Industry 4.0, FDM has been acknowledged as the technology in additive manufacturing (AM) machines which commonly used thermoplastic materials as feedstock filaments. Most of the research proved the benefits and improvement of the product from the application of composite material due to several factor such the lightweight character, partially recyclable nature, biodegradability and high specific strength as their advantage in industrial applications (Kumre *et al*., 2017). Therefore, the innovation material of composite filament for FDM becomes an interesting issue to be explored among the researchers.

However, there are three critical problems that should be addressed for composite material filaments, namely (1) mixing or compounding, (2) preparation of feedstock, and (3) manufacturing filament through extrusion machine (Sa'ude, 2016). First, the mixing and compounding phase is one of the most important parameters in material compounding. The requirement of the melting temperature of each material for the main matrix, filler and binder, is the core issue in composite materials. The compounding of various materials may involve certain mixing methods, where when the temperature selection over the melting temperature and some of the material weight is decreased and vaporised, the potential of material degradation is high. Furthermore, the mixing and filament extrusion phase temperature must be lower than the degradation temperature of the binder (Sa'ude *et al.*, 2014).

Then, the volume ratio of various materials such as matrix material, a conductive filler, and binder would provide a continuous linkage and efficient concentration for conductive composite material in a continuous network material for feedstock preparation (Sancaktar *et al.*, 2011). For volume ratio material preparation, the best formula and calculation provided a good interconnection between matrix and filler material to maintain the conductive portion with good flexibility, stiffness, and viscosity in filament manufacturing.

Next, homogeneous mixing and bonding material are some critical factors in the manufacture of filament. It can influence the conductive portion with constant viscosity in the manufacturing filament. Besides, the constant distribution of fibre-filled polymer matrix was important in mixing process. The filament in wire form was difficult in the manufacturing process when the matrix material is filled with high fibre material and produced as a brittle composite material. Therefore, some of the binder was added in a matrix material to minimise the brittle characteristic of that material and to improve the flow during the fabrication of filament (Sa’ude *et al.*, 2016, Mostaffa *et al.*, 2011).

The POFA has the potential as an effective reinforcement in thermoplastics materials. It was found on previous reports that there were numerous attempts on blending the biomass materials with a polymer to perform a composite material. However, by comparing to previous research, less research was conducted on making composite material that specifically focuses on the composite filament for FDM using the POFA reinforced with a polymer.

1.3 Objective

The primary goal of this research was to investigate the natural composite filament material for FDM use. These research objectives are as follows:

i. To investigate the best composition percentages of the POFA+PP+MAPP materials to be formed as a favourable result of filaments.

ii. To investigate the feasibility of POFA+PP+MAPP composite filament deposition using FDM machine.

iii. To evaluate the mechanical and observation defects of the deposited POFA+PP+MAPP samples.

1.4 Scope of the Study

These are the scope of the study:

i. 20%, 30%, 40%, 50%, and 60% volume percentage of POFA was used in the mixture process of POFA+PP+MAPP composite material.

ii. 5% and 8% volume percentage of MAPP was added in the mixture of POFA+PP+MAPP as compatibilizing agent to improve the bonding between fibre and polymer.

iii. Material preparation and compounding by the Brabender plastograph mixer of POFA+PP+MAPP filaments with sufficient melting temperatures and mixing times.

iv. The development of a new POFA+PP+MAPP filament wire (diameter: 1.75mm ± 0.02) with melting temperature at 170 to 190°C by the custom-made single extruder machine.

v. The development of sample (ISO527-1) for POFA+PP+MAPP filament on the FDM machine.

1.5 Significant of Study

The purpose of this research is to provide contributions in the manufacturing of FDM filament material specifically for composite filament material in terms of the bio-waste product by oil palm, which is POFA reinforced with polymer-based. The composite filament fabrication process parameter was studied in this research by gaining enough information in fabricating a new wire filament form that can be applied uniformly in FDM deposition.

At the end of this research, the expected outcomes of this study is the development of bio-waste filament material using POFA reinforced with PP as a new alternative composite filament material in Additive Manufacturing (AM) technology. In other words, a small effort in reduced the oil palm waste is believed to create a significant benefit to the environment and contribute to a more sustainable green technology.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a literature review was briefly covered all the important things related to the study from the previous studies and journal papers. On the other hand, it was highlighted the issue of material selection such as the main matrix, filler, and additive material in the composite material area. Then, the process involved in composite filament production and their application in FDM technology was critically reviewed as a guideline in the methodology process. Therefore, the combination of information and data collected in this chapter shows the research gap as a reference for the research process in this study.

2.1 Palm Oil in Malaysia

The species Elaeis guineensis (oil palm tree) is mainly planted in oil palm plantations in Malaysia (Keshvadi *et al.*, 2011). Malaysia has reached 4.98 million hectares of land devoted to the production of palm oil, recognised as one of the world's leading palm oil producers and exporters. The United States Department of Agriculture reported that by 2017, the global palm oil output was about 64.5 million tonnes and about 80% of the world palm oil production is from Malaysia and Indonesia (Garba *et al.*, 2019).

2.2 Oil Palm Issues

By successfully integrating the beneficiaries of the palm oil industry, Malaysia is one of the countries that have a responsibility for the global transformation of the oil palm industry through substantial contributions and persistent dedication (Awalludin *et al*., 2015). Undoubtedly, palm oil has become Malaysia's main agricultural crop and one of the biggest contributors to the country's economic growth (Jamilah *et al.*, 2019). While the industry is considered as financially secure and gives a considerable income to the economy, it also contributes a huge amount of palm oil biomass waste at the same time (Awalludin *et al*., 2015).

It has been estimated that approximately 7 tonnes of fibre, 25 tonnes of empty fruit bunches, and 20 tonnes of palm kernel shells are produced for every 100 tonnes of raw fruit bunches harvested (Iskandar *et al*., 2018). Besides, Ng *et al*. (2019) reported that the Malaysian Palm Oil Board (MPOB) has announced that Malaysia is capable of producing millions tonnes of palm oil per year, which has added a substantial amount of waste due to this massive production. In this industry, solid biomass waste is produced in two ways, which are from oil palm plantations and palm oil extraction plants.

As seen in Figure 2.1, waste in the form of harvested trunks (OPT) is available during replanting phase, while pruned fronds (OPF) are available during the fruit harvesting process. Meanwhile, in Figure 2.2, waste from palm oil extraction mills is derived from empty fruit bunches (EFB), palm kernel shell (PKS), and mesocarp fibre (MF). The EFB is produced after oil extraction, where the fresh fruit bunches are pressurised, cooked, and extracted from the bunch. The kernel shells are collected after the process of removing the nut from its kernel, while the mesocarp fibre is produced during the palm oil extraction process. However, the existence of such oil palm waste poses a significant waste disposal problem (Abdullah and Sulaiman, 2013).

REFERENCES

Abdullah, N. and Sulaiman, F. (2013). The Oil Palm Wastes in Malaysia. InTech; Biomass Now – Sustainable Growth and Use, 76-94.

Agro-Industrial Waste Sustainable Management (2017) – A Potential Source Of Economic Benefits To Palm Oil Mills In Malaysia. Journal of Urban and Environmental Engineering, vol. 11, num. 1, 108-118

Ahlhelm. (2015) Innovative and novel manufacturing methods of ceramics and metal–ceramic composites for bio-medical applications. Journal of the European Ceramic Society, 36, 2883–2888.

Ahmad B. Malkawi, Maan Habib, Yazan Alzubi, and Jamal Aladwan. (2020). Engineering Properties Of Lightweight Geopolymer Concrete Using Palm Oil Clinker Aggregate. International Journal of GEOMATE, Jan., 2020, Vol.18, Issue 65, 132-139.

Anitha, R., Arunachalam, S., and Radhakrishnan, P. (2001). Critical parameters influencing the quality of prototypes in fused deposition Modeling. Journal of Material Processing Technology, 118 (1–3), 385–388.

Arulraj, P. G. and Carmichael, J. M. (2011). Effect of nano-flyash on strength of concrete International journal of civil and structural Engineering 2, 475-486.

Ashfaque, A. J., Wan, I. G., Noridah, M., Samiullah, S., & Muhammad, T. L. (2018). Utilization of Palm Oil Fuel Ash and Eggshell Powder as Partial Cement Replacement - A Review. Civil Engineering Journal Vol. 4, No. 8, August, 1-9.

Awalludin, M. F., Sulaiman, O., Hashim, R., & Aidawati, W. N. (2015). An Overview Of The Oil Palm Industry In Malaysia And Its Waste Utilization Through Thermochemical Conversion, Specifically Via Liquefaction. Renewable and Sustainable Energy Reviews, 50, 1469–1484.

Bala, A.S., Wahab, S.B., and Ahmad, M.B. (2016). Elements and materials improve the FDM products: a review. Advanced Engineering Forum, ISSN: 2234-991X, 16.

Blanco, I. (2020). The Use of Composite Materials in 3D Printing. Journal of Composites Science, 4 (42), 1-22.

Boparai, K.S., Singh, R., and Singh, H. (2016). Modeling and optimization of extrusion process parameters for the development of Nylon6–Al–Al2O3 alternative FDM filament. Progress in Additive Manufacturing, 1, 115–128.

Boparai, K.S., Singh, R., and Singh, H. (2016). Wear behaviour of FDM parts fabricated by composite material feed stock filament. Rapid Prototyping Journal, 22 (2), 350–357.

Carlota, V. (2020). All you need to know about Polypropylene (PP) for 3D printing. 3D Natives: Your Source For 3D Printing. Retrieved from https://www.3dnatives.com/en/pp-3d-printing-material-130520204/

Carneiro, O. S., Silva, A. F., Gomes, R. (2015). Fused deposition modeling with polypropylene. Material Design; 83: 768-776.

Cheng, C., Abdullah, N., & Nasuha, S. (2018). Hydrogen production via CO_2 reforming of CH 4 over low-cost Ni / SBA-15 from silica-rich palm oil fuel ash (POFA) waste. ScienceDirect International Journal of Hydrogen Energy, 44(37), 20815–20825.

Chockalingam, K., Jawahar, N., and Praveen, J. (2016). Enhancement of anisotropic strength of fused deposited ABS parts by genetic algorithm. Materials and Manufacturing Processes, 31 (15), 2001–2010.

Costantino, M. A., Rosales, C., Pettarin, V. (2019.). Polypropylene Blends and Composite : Processing- Morphology- Performance Relationship of Injected Pieces. IntechOpen., 1-14.

Sivakumar, D., Hussain, F., Ng, L. F., Chua, J. W., & Dzulfakarudin, M. I. (2019). Tensile and Flexural Performance of Polypropylene Based Oil Palm Fibre

Reinforced Metal Laminates. International Review of Mechanical Engineering (I.RE.M.E.), Vol. 12, N. 2, 1-7.

Drummer, D., Cuellar, S. C., and Rietzel, D. (2012). Suitability of PLA/TCP for fused deposition Modeling. Rapid Prototyping Journal, 18 (6), 500–507.

Dul, S., Fambri, L., and Pegoretti, A. (2016). Fused deposition Modeling with ABS-graphene nano composites. Composites Part A: Applied Science and Manufacturing, 85, 181–191.

Elammaran, J., Rahman, M. R., Deshan, A. B., Muhammad, K. B., Akshay, K. and Afrasyab, K. (2020). Comparative Study of Fly Ash/Sugarcane Fiber Reinforced Polymer Composites Properties. BioResources 15(3), 5514-553.

Elina, I. (2017). Suitability Of Recycled PP For 3D Printing Filament. ARCADA, Plastic Technology, 1–48.

Filgueira, D., Holmen, S., Melbo, J. K., Moldes, D., Echtermeyer, A., & Chinga-Carrasco, G. (2018). 3D Printable Filaments Made of Biobased Polyethylene Biocomposites. Polymers, 10, 314; 2-15.

Faridah, M. M., Wan Ibrahim, W. A., Nodeh, H. R., Sutirman, Z. A., Ting, N. N., & Sanagi, M. M. (2018). Recent advances in the preparation of oil palm waste-based adsorbents for removal of environmental pollutants - a review. Malaysian J. Anal. Sci. 22, 175 – 184.

Francis, V., and Jain, P.K., (2016). Experimental investigations on fused deposition Modeling of polymer-layered silicate nano composite. Virtual and Physical Prototyping, 11 (2), 109–121.

Friedrich, B. and Engelbert, W., (2018). Correlations between Influencing Parameters and Quality Properties of Components Produced by Fused Deposition Modeling. Procedia CIRP 72 (2018) 1214–1219.

Garba, S., Iya, D., Noh, M. Z., Azureen, N., Kutty, A., Al, M., & Muhamad, A. (2019). Effect of Palm Oil Fuel Ash Treatment on Physico- Mechanical Properties of Porcelain. AIP Conference Proceedings 2068, 020093(February). http://doi.org/10.1063/1.5089392

Garg, A., Bhattacharya, A., and Batish, A. (2016). On surface finish and dimensional accuracy of FDM parts after cold vapour treatment. Materials and Manufacturing Processes, 31 (4), 522–529.

Garg, H., and Singh, R. (2016). Investigations for melt flow index of Nylon6-Fe composite based hybrid FDM filament. Rapid Prototyping Journal, 22 (2), 338–343.

Goyanes, A., Kobayashi, M. R., Martínez, P., Gaisford, S., Basit, A. W. (2016) Fused- filament 3D printing of drug products: microstructure analysis and drug release characteristics of PVA-based caplets. Int. J. Pharm, 514, 290-295.

Gray IV, R. W., Baird, D. G., and Bøhn, J. H. (1998). Effects of processing conditions on short TLCP fibre reinforced FDM parts. Rapid Prototyping Journal, 4 (1), 14–25.

Hassan, W. N. F. W., Ismail, M. A., Lee, H. S., Hussin, M. W., Ismail, M. A., & Singh, J. K. (2017). Utilization of Nano Agricultural Waste to Improve the Workability and Early Strength of Concrete. Int. J. Sus. Build. Technol. Urban Dev. 8, 316–331.

Wang, H., Ku, H., Pattarachaiyakoop, N., Trada, M. (2011). A Review on the Tensile Properties of Natural Fiber Reinforced Polymer Composites, Composite Part B Engineering, Vol. 42, n. 4, pp. 856–873.

Halimatuddahliana, N., Setaty, P., Maulida., & Mersi, S. S. (2015). Impact Strength And Thermal Degradation Of Waste Polypropelene/ Oil Palm Empty Fruit Bunch (OPEFB) Composites: Effect Of Maleic Anhydride Polypropylene (MAPP) Addition. Procedia Chemistry 16, 432-437.

Harper, L. T., Burn, D. T., Johnson, M. S., & Warrior, N. A. (2018). Long discontinuous carbon fibre/polypropylene composites for high volume structural applications. J Compos Mater;52:1155–70.

Hazman, S., Mohd Yasin, N. H., Takriff, M. S., Hasan, H. A., Kamarudin, K. F., & Mohd Hakimi, N. I. N. (2018). Integrated palm oil mill effluent treatment and CO_2 sequestration by microalgae. Sains Malaysiana. 47, 1455-1464.

Haruna Hamod (2014). The thesis of Suitability of recycled HDPE for 3D printing filament. ARCADA, Degree Thesis: Plastic Technology.

Heijenrath, R., and Pejis, T. (1996). Natural fibre mat reinforced thermoplastic composites based on flax fibres and polypropylene. Advanced Composite Letters, 5 (3), 81–85.

Hill, N., and Haghi, M. (2014). Deposition direction-dependent failure criteria for fused deposition Modeling polycarbonate.Rapid Prototyping Journal, 20 (3), 221–227.

Huang, S. H., Liu, P., Mokasdar, A., Hou, L. (2013). Additive Manufacturing And Its Societal Impact: A Literature Review. Int J Adv Manuf Technol 2013; 67(5–8):1191–203.

Hussein, M. H., Gul, A. J., Fadzil, M. Y., and Ali, M. H. (2018). Applications of Nano palm oil fuel ash and Nano fly ash in concrete. IOP Conf. Series: Materials Science and Engineering 342 (2018) 01206.

Ibrahim, I. D., Jamiru, T., Sadiku, R. E., Kupolati, W. K., & Agwuncha, S. C. (2017). Dependency of the mechanical properties of sisal fiber reinforced recycled polypropylene composites on fiber surface treatment, fiber content and nanoclay. J Polym Environ;25(2):427–34.

Iskandar, M. J., Baharuma, A., Anuar, F. H., & Othaman, R. (2018). Palm oil industry in South East Asia and the effluent treatment technology-A review. Environ Technol Innovat 9, 169-185.

Islam, U., Momeen, M., Mo, K. H., Alengaram, U. J., Jumaat, M. Z. (2016). Durability Properties of Sustainable Concrete Containing High Volume Palm OilWaste Materials. J. Clean. Prod. 137, 167–177.

Jamo, U. H. and Abdu S. G. (2015). Characterization of a Treated Palm Oil Fuel Ash. Science World Journal, 10(1), 27-31.

Garcia-Nunez, J. A., Rodriguez, D. T., Fontanilla, C. A., Ramirez, N. E., Lora, E. E. S., Frear, C. S., Stockle, C., Amonette, J., & Garcia-Perez, M. (2016).

Evaluation of alternatives for the evolution of palm oil mills into Biorefineries, Biomass Bioenergy 95, 310-329.

Jemimah, C. and Arulraj, P. (2012). Influence Of Nano Materials On Consistency, Setting Time And Compressive Strength Of Cement Mortar. Engineering Science and Technology, 2250-3498.

Kakou, C. A., Arrakhiz, F. Z., Trokourey, A., Bouhfid, R., Qaiss, A., & Rodrigue, D. (2014). Influence of coupling agent content on the properties of high density polyethylene composites reinforced with oil palm fibers, Materials and Design.

Keshvadi, A., Endan, J., Harun, H., Ahmad, D., & Saleena, F. (2011). The relationship between palm oil index development and mechanical properties in the ripening process of Tenera variety fresh fruit bunches. Res J Appl Sci Eng Technol;3:218–226.

Khalid, N. H. A., Rahman, A., Sam, M., & Mohamed, A. (2019). Properties of polymer concrete containing active micro filler of palm oil fuel ash IOP Conf. Series: Materials Science and Engineering 620 012065, 1-8.

Khan, J. A., Khan, M. A., & Islam, R. (2012) Effect of mercerization on mechanical, thermal and degrada- tion characteristics of jute fabric-reinforced polypropylene composites. Fibers Polym 13:1300–1309.

Kilole, T. C., Luca, F., & Nalankilli, G. (2017). Kaolinite/Polypropylene Nanocomposites. Part 3: 3D Printing. International Research Journal of Engineering and Technology (IRJET) Volume: 04 Issue: 11 Nov, 1-16.

Kiss, P., Stadlbauer, W., Burgstaller, C., & Archodoulaki, V. (2020). Development of high-performance glass fibre-polypropylene composite laminates : Effect of fi bre sizing type and coupling agent concentration on mechanical properties. Composites Part A, 138(July), 106056.

Khairunisa, M. , Jahangir, M., Azzimah, Z. , Warid, H., Anwar A. M., Andri, K., & Mokhtar, A. B. (2019). Properties of high strength palm oil clinker lightweight concrete containing palm oil fuel ash in tropical climate. Construction and Building Materials 199, 163–177.

Kufel, A., & Kuciel, S. (2019) Basalt/Wood Hybrid Composites Based On Polypropylene: Morphology, Processing Properties, And Mechanical And Thermal Expansion Performance. Materials (Basel);12, 2557.

Kumre, A., Rana, R. S., and Purohit, R. (2017). A Review On Mechanical Property Of Sisal Glass Fiber Reinforced Polymer Composites. Mater. Today-Proc. 4(2), 3466-3476.

Jamilah, S., Mohd, H., Zakaria, M. R., Roslan, A. M., Amiruddin, A., Ali, M., & Hassan, M. A. (2019). Oil Palm Biomass Biorefinery in Malaysia. Lignocellulose for Future Bioeconomy. Elsevier Inc. 12, 265-286.

Lee, J., and Huang, A. (2013). Fatigue analysis of FDM materials. Rapid Prototyping Journal, 19 (4), 291–299.

Lim, N. H. A. S., Ismail, M. A., Lee, H. S., Hussin, M. W., Sam, A. R. M., & Samadi, M. (2015). The Effects of High Volume Nano Palm Oil Fuel Ash on Microstructure Properties and Hydration Temperature of Mortar. Constr. Building Mater. 93, 29–34.

Lim, S. K., Tan, C. S., Lim, O. Y., & Lee, Y. L. (2013) Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. Constr. Build Mater 46:39–47.

Malkawi, A., Habib, M., Alzubi, Y., & Aladwan, J. (2020). Engineering Properties of Lightweight Geopolymer Concrete Using Palm Oil Clinker Aggregate. International Journal of GEOMATE, Jan., 2020, Vol.18, Issue 65, 132-139.

(MPOB).Overview of the Malaysian Oil Palm Industry (2017). Available at: (http://bepi.mpob.gov.my/images/overview/Overview_of_Industry_2017.pdf); 2018.

Magazine Scientific Malaysian, Raymond, C. (2017): Palm Oil And The Environment. Available at: (https://magazine.scientificmalaysian.com/issue-13-2017/palm-oil-and-the-environment/).

Mahmood, A. A., Khazal, M., Nordzaima, S., & Mohamad, A. (2019). Materials Today : Proceedings Use of palm oil fuel ash (POFA) -stabilized Sarawak peat composite for road subbase. Materials Today: Proceedings, 1-7.

Mazzanti, V., Malagutti, L., & Mollica, F. (2019). FDM 3D Printing of Polymers Containing Natural Fillers: A Review of their Mechanical Properties. Polymers, 11, 1094, 1-22.

Milosevic, M., Stoof, D., Pickering, K.L. (2017). Characterizing the mechanical properties of fused deposition Modeling natural fiber recycled polypropylene composites. J. Compos. Sci., 1-7.

Mohamad, M. E., Mahmood, A. A., & Yee Min, A. Y. (2018). Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) as Partial Replacement for Cement in Concrete. E3S Web of Conferences 34, 01004, 1-7.

Mohan, N., Senthil, P., Vinodh, S. & Jayanth, N. (2017). A review on composite materials and process parameters optimisation for the fused deposition Modeling process, Virtual and Physical Prototyping ,1-13.

Muthusamy, K., Mirza, J., Azzimah, N., Warid, M., Abdul, A. P. P., Kusbiantoro, A., & Budiea, A. (2019). Properties of high strength palm oil clinker lightweight concrete containing palm oil fuel ash in tropical climate. Construction and Building Materials, 199, 163–177.

Nerenz, B. A., Fuqua, M. A., Chevali, V. S., Ulven, C. A. (2012). Processing and characterization of a polypropylene biocomposite compounded with maleated and acrylated compatibilizers. Int J Polym Sci 2012, 1-7.

Ng, M. H., Verma, D., Sabu, T., & Goh, K. L. (2019). Characteristics of Johorean Elaeis guineensis oil palm kernel shells: elasticity, thermal stability, and biochemical composition. Biomass, Biopolymer-Based Materials, and Bioenergy. Elsevier Ltd, 75-86.

Ning, F., Cong, W., Qiu, J., Wei, J., & Wang, S. (2015). Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. Compos Part B;80:3,69–78.

Ning, F., Cong, W., Qiu, J., Wei, J., & Wang, S. (2016). Additive manufacturing of carbon fibrereinforced plastic composites using fused deposition Modeling: effects of process parameters on tensile properties. Journal of Composite Materials,1-7.

Noh, M. Z., Jamo, H. U., & Ahmad, Z. A. (2017). The Bending Strength of the Porcelain with the Substitution of Quartz by Palm Oil Fuel Ash. Materials Science Forum Vol. 888, 112–116.

Marwah, O. M. F., Halim, N. F. A., Shukri, M. S., Mohamad, E. J., and Ibrahim, M. A. (2016) Study On Palm Fiber Reinforces As A Filament In Portable FDM. ARPN Journal of Engineering and Applied Sciences vol. 11, no. 12 ,7828-7834.

Ochi, S. (2015). Flexural properties of long bamboo fibre/PLA composites. Open Journal of Composite Materials, 5, 70–78.

Osman, M. A., Atia, M. R. A. (2018). Investigation of ABS-rice straw composite feedstock filament for FDM. Rapid Prototyp. J., 24, 1067–1075.

Rajak, M. A. A., Majid, Z. A., Ismail, M. (2015). Morphological Characteristics of Hardened Cement Pastes Incorporating Nano-Palm Oil Fuel Ash. Proced. Manuf. 2, 512–518.

Pandey, J. K., Nagarajan, V., Mohanty, A. K., & Misra, M. (2015). Commercial potential and competitiveness of natural fiber composites. Biocomposites: Design and Mechanical Performance (Fourteenth Edition). Elsevier Ltd. 1-9.

Plymill, A. (2016). Graphene and carbon nano-tube PLA composite feedstock development for fused deposition modelling. University of Tennessee Honors Thesis Projects.

Razi, P. Z., Abdul Razak, H., and Khalid, N. H. A. (2016). Sustainability, eco-point and engineering performance of different workability OPC fly-ash mortar mixes, Materials 9(5), 1-28.

Rahman, R., Hamdan, S., Jayamani, E., Kakar, A., Khusairy, M., Bakri, B., & Yusof, B. (2019). The Effect Of Palm Oil Fuel Ash (POFA) And Polyvinyl Alcohol

(PVA) On The Physico-Mechanical, Thermal And Morphological Properties Of Hybrid Bio-Composites. Springer Nature : Polymer Bulletin, 1-13.

Rajak, M. A. A., Majid, Z. A., Ismail, M. (2015). Morphological Characteristics of Hardened Cement Pastes Incorporating Nano-Palm Oil Fuel Ash. Proced. Manuf. 2, 512–518.

Rubinsin, N. J., Ramli, W., Daud, W., Kamarudin, S. K., Masdar, M. S., Rosli, M. I., & Lim, K. L. (2019). Optimization Of Oil Palm Empty Fruit Bunches Value Chain In Peninsular Malaysia. Journal Pre-proof. Food and Bioproducts Processing, 1-34.

Sa'ude, N., Ibrahim, M. & Ibrahim, M. H. I. (2016). Melt Flow Index of Recycle ABS for Fused Deposition Modeling (FDM) Filament. Applied Mechanics and Materials Vols. 773-774, 3-7.

Sa'ude, N., Ibrahim, M. & Ibrahim, M. H. I. (2016). Melt Flow Rate (Mfr) Of Abs-Copper Composite Filament By Fused Deposition Modeling (FDM). ARPN Journal of Engineering and Applied Sciences, vol. 11, no 10 (2016), 6562-6567.

Setiabudi, H. D., Cheng, C. C., Abed, S. M., The, L. P., & Chin, S. Y. Comparative study of Ni-Ce loading method: beneficial effect of ultrasonic assisted impregnation method in CO2 reforming of CH4 over Ni-Ce/SBA-15. J Environ Chem Eng 2018;6, 743-753.

Shamsuri, A. A. (2019). Important Criteria for Preparation of 3D Printer Filaments from Polymer Biocomposites, 4–6. SVOA Materials Science and Technology vol 1:1, 1-3.

Shubhra, Q. T. H., Alam, A.,& Quaiyyum M.A. (2011). Mechanical properties of polypropylene composites: A review. Journal of Thermoplastic Composite Materials 26(3) 362–391.

Shulga, E., Karamov, R., Sergeichev, I. S., & Konev, S. D. (2020.). Fused Filament Fabricated Polypropylene Composite Reinforced by Aligned Glass Fibers. Materials, 13 (3442), 1–9.

Sia, C.V., Nakai, Y., Tanaka, H., and Shiozawa, D. (2014). Interfacial fracture toughness evaluation of Poly(L-lactic acid)/Natural fibre composite by using double shear test method. Open Journal of Composite Materials, 4, 97–105.

Silva, A. F., Carneiro, O. S., Gomes, R. (2017). 3D Printing of Polypropylene Using the Fused Filament Fabrication Technique. AIP Conf. Proc., 1896, 1–5.

Singh, R., and Singh, S. (2015). Experimental investigations for statistically controlled solution of FDM assisted Nylon6-Al- Al2O3 replica based investment casting. Materials Today:Proceedings, 2, 1876–1885.

Sobuz, H. R., Hasan, N. S., Tamanna, N., & Islam, S. (2014). Structural Lightweight Concrete Production by Using Oil Palm Shell. Journal of Materials, Volume 2014, 1-7.

Sodeifian, G., Ghaseminejad, S., & Yousefid, A. A. (2019). Physics Preparation of polypropylene/short glass fiber composite as Fused Deposition Modeling (FDM) filament. Results Phys., 12, 205–222.

Spoerk, M., Gonzalez-Gutierrez, J., Lichal, C., Cajner, H., Berger, G. R., Schuschnigg, S., Cardon, L., & Holzer, C. (2018). Optimisation of the Adhesion of Polypropylene-Based Materials during Extrusion-Based Additive Manufacturing. Polymers, 10, 490-498.

Stepashkin, A., Chukov, D. I., Senatov, F. S., Salimon, A., Korsunsky, A., & Kaloshkin, S. (2018). 3D-printed PEEK-Carbon Fiber (CF) composites: Structure and thermal properties. Compos Sci Technol; 164: 319-326.

Stoof, D. and Pickering, K. (2018). Sustainable composite fused deposition Modeling filament using recycled pre-consumer polypropylene. Composites Part B, 135 (October 2017), 110–118.

Stoof, D., and Pickering, K. L. (2017). 3D Printing of natural fibre reinforced recycled polypropylene.Processing and fabrication of advanced materials-XXV. The University of Auckland.

Tangchirapat,W., Khamklai, S., & Jaturapitakkul, C. (2012). Use of Ground Palm Oil Fuel Ash to Improve Strength, Sulfate Resistance, andWater Permeability of Concrete Containing High Amount of Recycled Concrete Aggregates. Mater. Des, 41, 150–157.

Tekinalp, H.L. (2014). Highly oriented carbon fibre–polymer composites via additive manufacturing. Composites Science and Technology, 105, 144–150.

Thomas, B. S. Kumar, S. Arel, H. S. (2017). Sustainable Concrete Containing Palm Oil Fuel Ash as a Supplementary Cementitious Material—A Review. Renew. Sustain. Energy Rev., 80, 550–561.

Tian, X., Liu, T., Yang, C., Wang, Q., & Li, D. (2016) Interface and performance of 3D printed continuous carbon fibre reinforced PLA composites. Composites Part A: Applied Science and Manufacturing, 1-8.

Trisakti, B., Mhardela, P., Husaini, T., Irvan, & Daimon, H. (2018). Production of oil palm empty fruit bunch compost for ornamental plant cultivation, in: IOP Conference Series: Materials Science and Engineering. 309(1), 1-8.

Umar, M. S., Urmee, T., & Jennings, P. (2018). A policy framework and industry roadmap model for sustainable oil palm biomass electricity generation in Malaysia. Renew. Energy. 128, 275-284.

Varga, L. J and Barany, T. (2020). Development of Polypropylene-Based Single-Polymer Composites With Blends of Amorphous Poly-Alpha-Olefin and Random. Polymers, 12, 1429-1443.

Wang, P., Zou, B., Ding, S., Huang, C., Shi, Z., Ma, Y., & Yao, P. (2020). Preparation of short CF/GF reinforced PEEK composite filaments and their comprehensive properties evaluation for FDM-3D printing, Composites Part B 1-36.

Wang, X., Jiang, M., Zhou, Z., Gou, J. and Hui, D. (2017). 3D Printing Of Polymer Matrix Composites: A Review And Prospective. Composites Part B, Vol. 110, 442-458.

Wei, L. T. , Han, S. L. , Vanissorn, V. , Trevor H. J. K. S., Wan N. F. W. H. , Mohamed A. I., Asiful H. S. , and Nabeel A. (2019). Optimization of Micro and Nano Palm Oil Fuel Ash to Determine the Carbonation Resistance of the Concrete in Accelerated Condition. Materials, 12, 130-139.

Wi, K., Lee, H. S., Lim, S., Song, H., Hussin, M. W., Ismail, M. A. (2018). Use of an Agricultural By-product, Nano Sized Palm Oil Fuel Ash as a Supplementary Cementitious Material. Constr. Build. Mater., 183, 139–149.

Wu, C., Liao, H., & Cai, Y. (2017). Characterisation, Biodegradability And Application Of Palm Fibre reinforced Polyhydroxyalkanoate Composites. Polymer Degradation and Stability, 140 (2017), 55-63.

Wu, Q., Qiang, T. C., Zeng, G., Zhang, H., Huang, Y., & Wang, Y. (2017). Sustainable and renewable energy from biomass wastes in palm oil industry: A case study in Malaysia. Int. J. Hydrogen Energy. 42, 23871-23877.

Xin, W., Man, J., Zuowan, Z., Jihua, G., & David, H. (2017). 3D printing of polymer matrix composites: A review and prospective. Composites Part B 110, 442-458.

Yi, S., Xu, S., Fang, Y., Wang, H., & Wang, Q. (2017). Effects of matrix modification on the mechanical properties of wood–polypropylene composites. Polymers 2017, 9, 712-720.

Zhao, D. (2015). Study on the Preparation of Bamboo Plastic Composite Intend for Additive Manufacturing. Key Engineering Materials, 667, 250–258.

Zhang, L., Xu, C. & Champagne, P. (2010). Overview of recent advances in thermo-chemical conversion of biomass. Energy Convers. Manag. 51, 969–982.