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Material Characterizations of the Polymers Reinforced with Recycled Flexible Plastic Blends as Filament for 3D Printing

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ABSTRACT

The high consumption of single-use plastics and the low recycling rates have seriously polluted the soil and ocean environments. Thermoplastic materials from recycling can be used to make filaments for 3D printing. This study is focused on preparing, characterizing, and comparing the polymers reinforced with recycled flexible plastic blends to be used as a filament in additive manufacturing. In this regard, two types of polymers were used to create the filament: High-Density Polyethylene (HDPE) and Polypropylene (PP), which were mixed with recycled flexible plastic (RF). The mixture was initially used to create filament byusing a single extrusion machine, with various ratios of virgin HDPE and PP to recycled flexible plastic (in weight%) at temperatures of 190°C and 230°C. Then, the filament blends were characterized using infrared (IR) spectroscopy, thermogravimetric analysis (TGA), and field emission scanning electron microscopy (FESEM). TGA analyses revealed that RF can increase the thermal stability of V-HDPE and V-PP upon blending, and HDPE/RF blends show a higher decomposition temperature than PP/RF. FESEM indicated that adding 30% RF is the best percentage for both polymer blends where the structure appears ductile. It can be concluded that the HDPE 70% blend is suitable for 3D printer filament as it showed the best decomposition temperature and the ductility of the fracture structure, which meet the requirements for 3D printer filament.

1. Introduction

Over the past 60 years, plastics have evolved into a product with many characteristics, uses, and applications. Throwing plastic into the environment has caused several related issues. Plastic trash contamination is now universally acknowledged to be a serious environmental problem.

Less than half of the almost 280 million tons of plastic generated worldwide are used for various applications, and the remaining litter the earth's oceans and continents [1,2]. Data shows that the most significant problems are plastics made from HDPE, LDPE, PP, and PVC, which are primarily used

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in manufacturing and cause greenhouse gas emissions [3]. The high consumption of single-use plastics and the low recycling ratesseriously polluted the soil and ocean environments [4].

Food plastic packaging has developed into a crucial component of prosperous food sectors that provide fast food, on-the-go beverages, prepared snacks, and meals, among other things [5]. Recycling is the most effective method for dealing with pollution and reusing materials to manufacture new products. Still, its success is highly dependent on public awareness, economic sustainability, and the establishment of public infrastructures [6]. Reusing polymeric materials from waste offers them a second life and allows for efficient waste management to produce consumable goods [7]. Thermoplastic materials from recycling can be used to make filaments for 3D printing, which was rapidly expanding in the market as noted by Misran *et al.*, [8].

The usage of PP in 3D printing is not very common. It tends to warp, which makes printing onit challenging. PP material requires a heated build volume and a relatively high build plate temperature [9]. The utilization of HDPE material for 3D printer filament is difficult to find because of the quality and processing barriers. Therefore, some of the studies have been reviewed. Based on research conducted by Beachler *et al.,* [10], the analysis was to verify whether HDPE filament could feed into the 3D printer. The outcome shows that testing techniques of diametrical consistency were required. Uniform and consistent dimension of the filament is an important factor in designing and analysing polymer plastic using CAD/CAE software as mentioned by Nuhu *et al.,* [11].

This research focuses on preparing and characterizing polymers reinforced with recycled flexible plastic blends as filaments in additive manufacturing. The experiment was carried out using the different percentage compositions of the recycled flexible plastic with virgin Polyethylene (PP) and High-density polyethylene (HDPE). The purpose of using the various percentages of recycled flexible plastic is to identify the reinforcement effects of the polymer blends towards the virgin polymer through physical, chemical, and thermal characterization.

2. Experimental

2.1 Material

Flexible plastic packaging HDPE, such as plastic bags and packaging wraps from post-consumer waste (PCW), was collected manually. Commercial virgin of High-density polyethylene (HDPE, MFR (190°C/2.16kg) 23g 10 min^1) and Polypropylene (PP, MFR (230°C/2.16kg) 0.95g 10 min^3) were purchased by Dear Venture SDN. BHD.

2.2 Preparation of High-Density Polyethylene Based Recycled Polymer

All the post-consumer flexible plastic packaging waste was washed with water and dried in direct sunlight for three hours. The dried flexible plastic packaging was melted using a milling roller to transform into a plastic plate. The plastic plates were shredded using a machine (Untha LR630) equipped with a 20-mm sieve to form the plastic pallets. The plastic pallets were then blended using an analytical mill (IKA A 10 Basic) until the plastic pallets became powder. The powder pallets were heated to 30°C within 2 hours to remove the moisture. The powder was mixed with virgin HDPE and PP and placed into a single extruder (Noztex Xcalibur) to become the filament. Figure 1, shows the prepared 3D printer filament with the ratios for virgin HDPE and PP to recycled flexible HDPE (in weight%) being 100:0, 0:100, 70:30, and 30:70 and the approximate diameter around 2.3 mm. The HDPE/RF and PP/RF blends ratio in Table 1 is referred to the study conducted by Al-Salem *et al.,* [12].

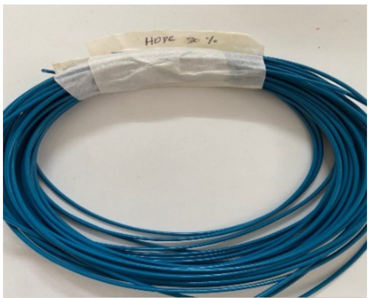
Filament	Ratio
	PP/RF 70:30
	PP/RF 30:70
	HDPE/RF 70:30
	HDPE/RF 30:70

Fig. 1. 3D printer filament of HDPE/RF and PP/RF blends ratio

Table 1 summarizes the virgin and recycled materials' feed ratios (in wt%).

Table 1
Feed ratios (in wt%) of the virgin and recycled materials

Sample	Virgin Polyolefin (%)		Post-consumer waste (%)
	HDPE	PP	Recycled Flexible Plastic (RF)
HDPE	100		
PP		100	
RF			100
HDPE 70 / RF 30	70		30
HDPE 30 / RF 70	30		70
PP 70 / RF 30		70	30
PP 30 / RF 70		30	70

Figure 2 represents the overall process of obtaining 3D printer filament from recycled polymer-based blends.

Fig. 2. Process of creating 3D printer filament of HDPE/RF and PP/RF blends

2.3 Characterization

2.3.1 Structural characterization

Fourier-transform infrared spectroscopy (FTIR) technique was developed in the field of plastic recycling because it affords the identification of mixed plastics. An FTIR Spectrometer Spectrum 2 was used to analyse the homogeneity of different polymer blends identification of the HDPE and PP functional groups in the virgin and recycled flexible plastic blends. The FTIR analysis can also give information concerning the homogeneity of different blends and allow for further identification of the polymers present. The FTIR spectra with percentage transmittance (%T) versus wavelength (cm^{-1}) were recorded within the 650 cm^{-1} - 4000 cm^{-1} scanning range.

2.3.2 Thermal stability characterizations

Thermogravimetric analysis (TGA) will be conducted using STA 2500 Regulus Simultaneous Thermal Analysis in an open aluminium crucible. The mass of each sample in all TGA experiments measured was 10 mg. The temperature ranged from 30°C to 600°C at a heating rate of 10 K/min. The temperature was held constant for 56 minutes, the percentage of mass change was measured, and then the raw data were transferred and re-drawn by Origin software. Water uptake experiments will be performed at 50°C and 50% relative humidity. The provided system software measures the percentage of mass change.

2.3.3 Morphological structure characterization

The morphology of the fracture surface of the filament, which was sputter-coated with a finelayer of platinum in an G20 ion Sputter coater (ISC-2020-0201), were observed using a scanning electron microscope (SEM) (Thermo Scientific Quattro S) at magnification 100x. The elemental composition was carried out using Energy Dispersive Spectroscopy (EDXS, OXFORD Instruments, Ultimax 40) to examine the elemental content in the plastic blends.

3. Result and Discussion

3.1 Structural Properties

To investigate the mixing compound and structure stability of the filament blends, FTIR was tested to see clearly whether bonds were formed after mixing processes. Figure 3 presents the FTIR spectra of HDPE/RF and PP/RF blends within the 650 cm^{-1} – 4000 cm^{-1} regions. Spectra of the material showed similar peaks among the filament blends. However, in the case of RF, significantly low intensities of peaks were indicated because of the presence of additive during manufacture [13]. Refer to Figure 3-Ai, it was found that the absorption bands at 1470 cm^{-1} were attributed to (CH_2) bending with scissoring vibrations of methylene group for all filament blends, while the absorption band around 720 cm^{-1} was reflects to (C=C) bend with rocking vibrations [14]. Referring to Figure 3-Aii, the absorption band of (-OH) was observed from 3700 cm^{-1} – 3547 cm^{-1}. The degradation of polyethylene caused by oxidation, which results in the generation of hydroperoxides and carbonyl, is indicated by the bands around 3348 cm^{-1} and 1736 cm^{-1} respectively.

The crystallinity of polyethylene was observed at the absorption band of 719 cm^{-1} and 729 cm^{-1} as generally obtained by Xiao *et al.,* [13]. An additional absorption band around 730 cm^{-1} is present in HDPE 30% and HDPE 70% but absent in V-HDPE blends as referred to the Silverstein *et al.*, [15] finding. This addition band might relate to addictive attributes to functional groups of carbonate ions (CO_3^{-2}) [16]. The absorption at 2800 cm^{-1} - 3000 cm^{-1} corresponding to the polyethylene bone shows the asymmetric and symmetric stretching of the (-C-H) bond of methyl group, as the main component of HDPE is aliphatic hydrocarbons, alkanes, and alkenes [17]. Meanwhile, it was noticed that the decreased intensity of this peak of the HDPE 70% blend was due to the reduced concentration of the methyl group.

Referring to Figure 3-Bi, it was found that the absorption bands at 1456 cm^{-1} - 1376 cm^{-1} were associated to the ($-CH_3$) bending and deformation of (CH_2) as the concentration of alkenes increases of all filaments blends as compared to RF. The absorption bands at 998 cm^{-1}, 972 cm^{-1} and 842 cm^{-1} show isotactic polypropylene bands of all blends, and these bands were absent in RF as they had different types of polymers. The blends exhibited the addition of band at 842 cm^{-1}, which was attributable of (C-H) group in calcium carbonate.

Meanwhile, the filament blends show a low peak intensity at 731 cm^{-1} and 719 cm^{-1}, reflecting the (C=C) band with rocking vibrations. This was due to the low molecular weight contaminants from RF and caused by addiction. This should not be present in PP homopolymers but commonly found in PE materials as compared to V-HDPE and may be present in PP polymers with an extremely low intensity because the ethylene unit was not in high concentration [18, 19]. The absorption band at 2839 cm^{-1} of PP 30% blend indicates low intensity compared to PP 70% and V-PP blends as it associated with the (CH_2) of alkene of amine acid. Meanwhile, the absorption band at 1167 cm^{-1} indicates the (C=C) bond, the backbone of Polypropylene itself had been explained by Prabowo *et al.,* [20]. The absorption band at 3300 cm^{-1} corresponds to polyamide-typical (N-H) stretching vibrations [18, 19] and the presence of peaks at 3398 cm^{-1} and 3200 cm^{-1} has been linked to surface-bound fatty amide slip agents [21, 22]. The absorption of (OH) group as refer to Figure 3-Bii, started the band at 3700 cm^{-1} to 3200 cm^{-1} in all filament blends. The surface-bound water may contain hydroxyl groups and hydrogen bonds that give rise to broad IR bands over 3000 cm^{-1}.

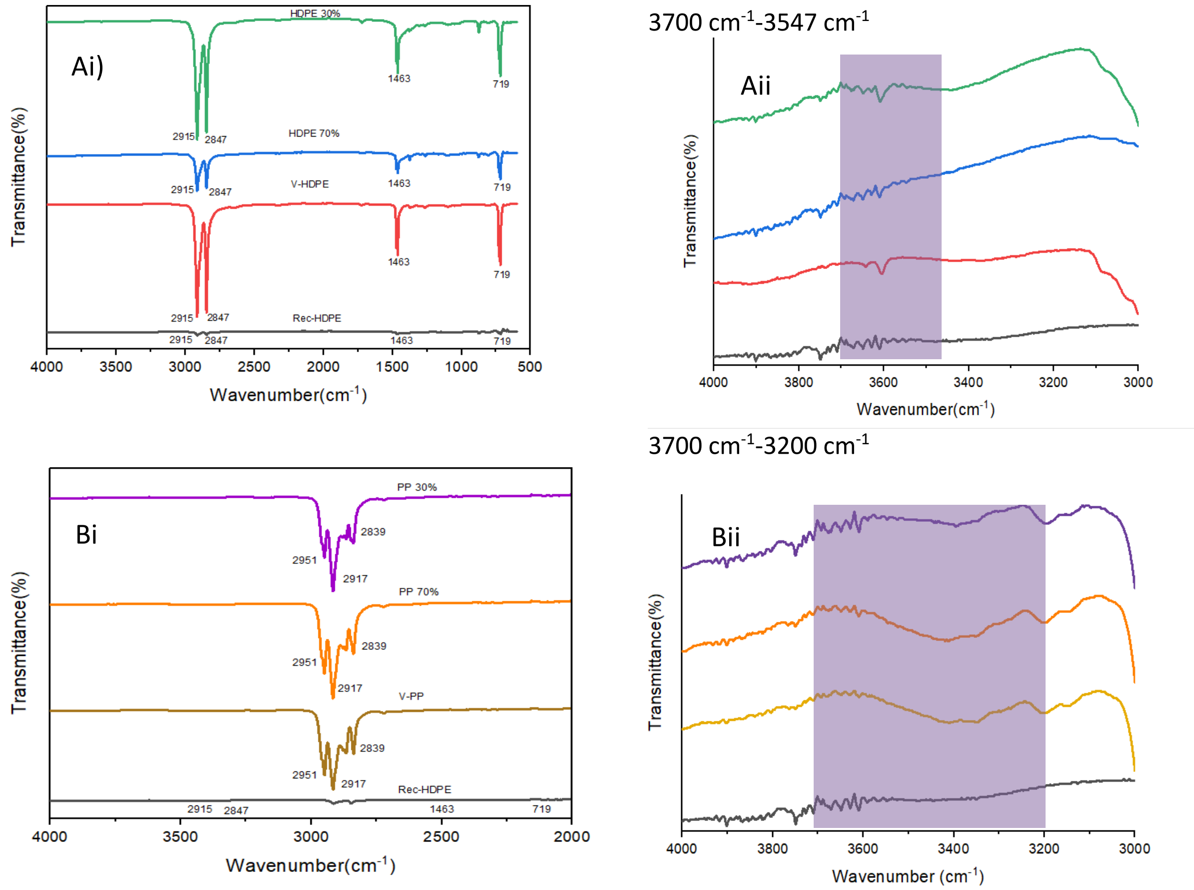


Fig. 3. Chemical properties of polymer blends: Ai) Whole FTIR graph for HDPE/RF, Aii) OH absorption for HDPE/RF, Bi) Whole FTIR graph for PP/RF, and Bii) OH absorption for PP/RF

However, significant differences in the spectra of filament blends compared to virgin polymers were found when the spectroscopic data of both the examined polymers were analysed. Since there was no splitting of the carbonyl peak as revealed by Harynska *et al.,* [23], the mixing operation did not result in re-crystallization. Further, minor changes in their peak intensity and band in specific blends were caused by the mixing of RF. Hence, the structural stability of both studied materials under given blend conditions can be pre-confirmed. The FTIR peak assignments for virgin, RF, HDPE/RF, and PP/RF blends were summarized in Table 2 and 3.

Table 2
FTIR peak assignments for virgin, RF and HDPE/RF blends

Wavenumber	Bonding	Vibration Type	Assigned to
2915 cm^{-1}	-C-H	Stretching (Asymmetric)	RF, V-HDPE, HDPE 70%, and HDPE 30%
2847 cm^{-1}	-C-H	Stretching (Symmetric)	RF, V-HDPE, HDPE 70%, and HDPE 30%
1473 cm^{-1}	CH_2	Bending (Asymmetric)	RF, V-HDPE, HDPE 70%, and HDPE 30%
1463 cm^{-1}	CH_2	Bending (Symmetric)	RF, HDPE 70%, and HDPE 30%
875 cm-^{1}	-C-H	Bending	RF, V-HDPE, HDPE 70%, and HDPE 30%
719 cm-^{1}	CH_2	Bending (Rocking)	RF, HDPE 70%, and HDPE 30%

Table 3
FTIR peak assignments for virgin, RF and PP/RF blends

Wavenumber	Bonding	Vibration Type	Assigned to
2951 cm^{-1}	CH_3	Stretching (Asymmetric)	V-PP, PP 70%, and PP 30%
2917cm^{-1}	CH_2	Stretching (Asymmetric)	V-PP, PP 70%, and PP 30%
2839 cm^{-1}	CH_2	Stretching	V-PP, PP 70%, and PP 30%
1456 cm^{-1}	CH_3	Bending (Symmetric)	V-PP, PP 70%, and PP 30%
1376 cm^{-1}	CH_3	Bending (Symmetric)	V-PP, PP 70%, and PP 30%
1167 cm^{-1}	C=C	Bending	V-PP, PP 70%, and PP 30%
998 cm^{-1}	C=C	Bending	V-PP, PP 70%, and PP 30%
972 cm^{-1}	C=C	Bending	V-PP, PP 70%, and PP 30%
875 cm^{-1}	C=C	Bending	RF, PP 70%, and PP 30%
842 cm^{-1}	C-H	Bending	V-PP, PP 70%, and PP 30%

3.2 Thermal Properties

TGA analysis was performed on HDPE/RF and PP/RF filament blends. The TGA and DTG thermographs for blends, respectively, are shown in Figure 4 and Figure 5. In Figure 4-Ai and Aii, the highest weight loss of the HDPE sample is V-HDPE, indicated at 101.51%, and the lowest weight loss is HDPE 30%, which is 82.17%, while HDPE 70% shows a reading of 82.59%. It can be concluded that weight loss was reduced when the percentage of RF increases. The thermal decomposition temperature of the filament blends was higher than that of V-HDPE and decreased with the addition of RF at 30% and 70%. Since recycling and regeneration have been shown to have a negative impact on the long-term qualities of HDPE, it is crucial to determine its thermal stability [24]. The decomposition of HDPE and PP filament blends was characterized by a single-step process, as referred to Figure 4, because the bond formation was more substantial between both polymers [25]. Referring to Figure 4-Bi and Bii, it was discovered that the weight loss was 88.36% (PP 30%), 90.90% (PP 70%), and 101.51% (V-PP). PP 30% indicates a less dramatic weight loss than V-PP and PP 70%. The V-PP sample was found to have the lowest decomposition temperature (423.8% °C), whereas PP 70% had the greatest decomposition temperature.

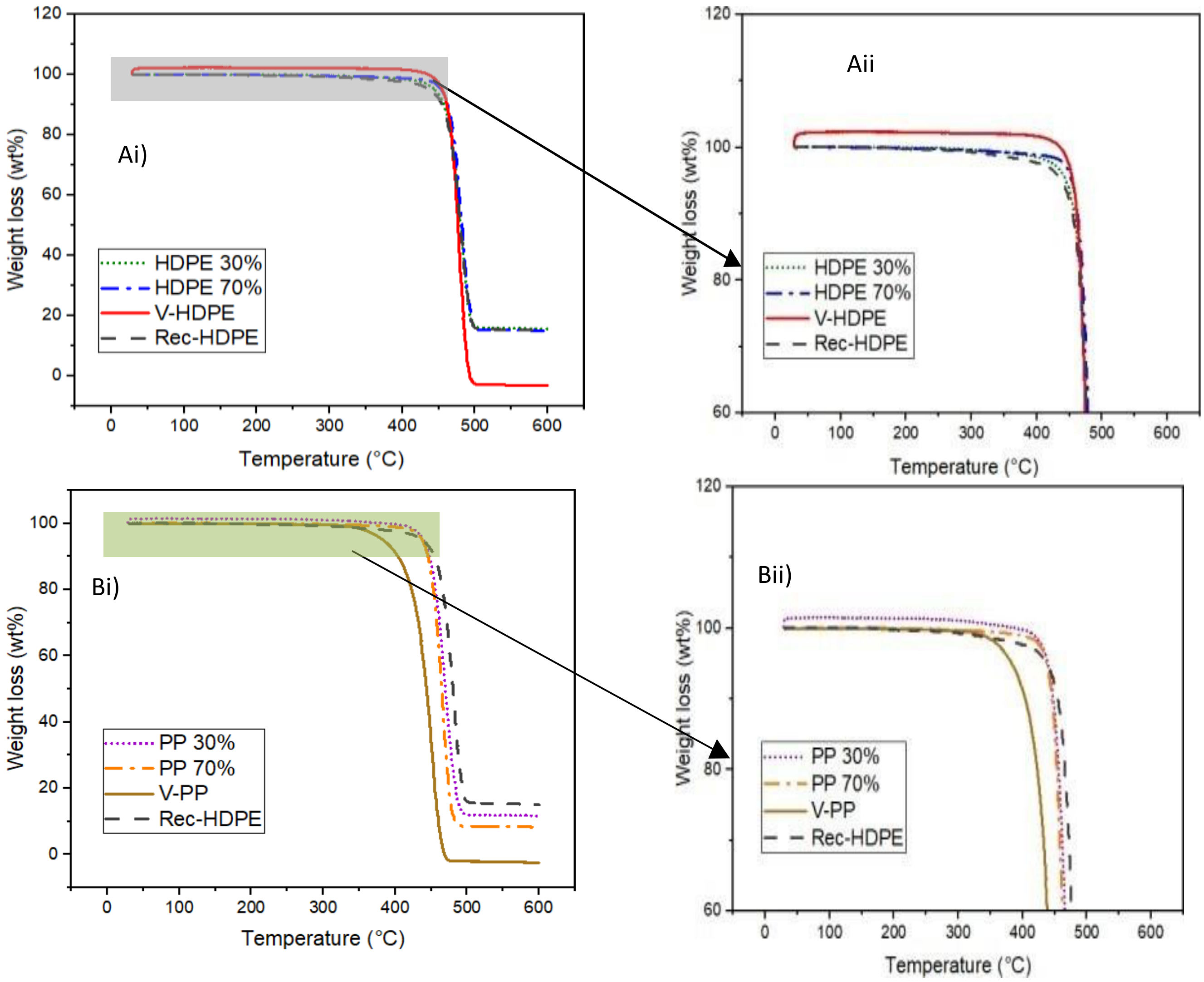


Fig. 4. Thermal properties of polymer blends: Ai) entire temperature change for HDPE/RF, Bi) entire temperature change for PP/RF, Aii) magnification of the initial temperature of decomposition for HDPE/RF and Bii) magnification of the initial temperature of decomposition for PP/RF

The material's copolymeric structure influenced the decomposition temperatures. In contrast to the PP 70% and PP 30% samples, the V-PP sample, for example, showed a more significant percentage of plasticity, which was associated with a drop in the thermal. These are backed up by Yao *et al.,* [26] and Noorul *et al.,* [27] who discovered that the structure of materials is an essential factor in determining thermal destruction. Moreover, the thermal decomposition of the blend sample ended at higher temperatures than V-PP. Table 4 provides a summary of the TGA analysis parameters, including the initial decomposition temperature (IDT), final decomposition temperature (FDT), maximum temperature (Tmax), and amount of char residue.

Table 4
Thermal properties of virgin, RF, HDPE/RF and PP/RF blends

Sample (%)	IDT (°C)	FDT (°C)	Tmax (°C)	RWL (%/min)	WL (%)	Residue(wt.%)
RF	461.8	492.7	481.3	27.13	81.80	14.95
V-HDPE	464.4	488.9	477.7	40.22	103.87	3.23
HDPE 70	466.0	493.2	482.9	31.43	82.59	14.98
HDPE 30	462.1	492.6	481.7	27.55	82.17	15.54
V-PP	428.8	464.2	451.3	25.58	101.51	2.52
PP 70	449.4	477.4	469.6	32.07	90.90	8.19
PP 30	449.4	485.1	466.3	25.30	88.36	11.57

It can be suggested that HDPE and PP blends with 70% virgin content, respectively were thermally stable (Figure 5).

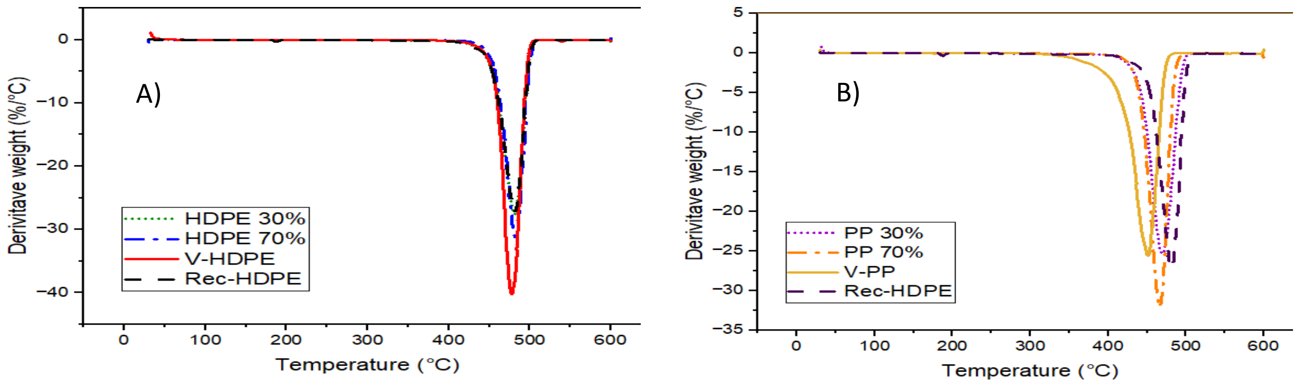


Fig. 5. Thermal properties of polymer blends: A) DTG for HDPE/RF and B) DTG for PP/RF

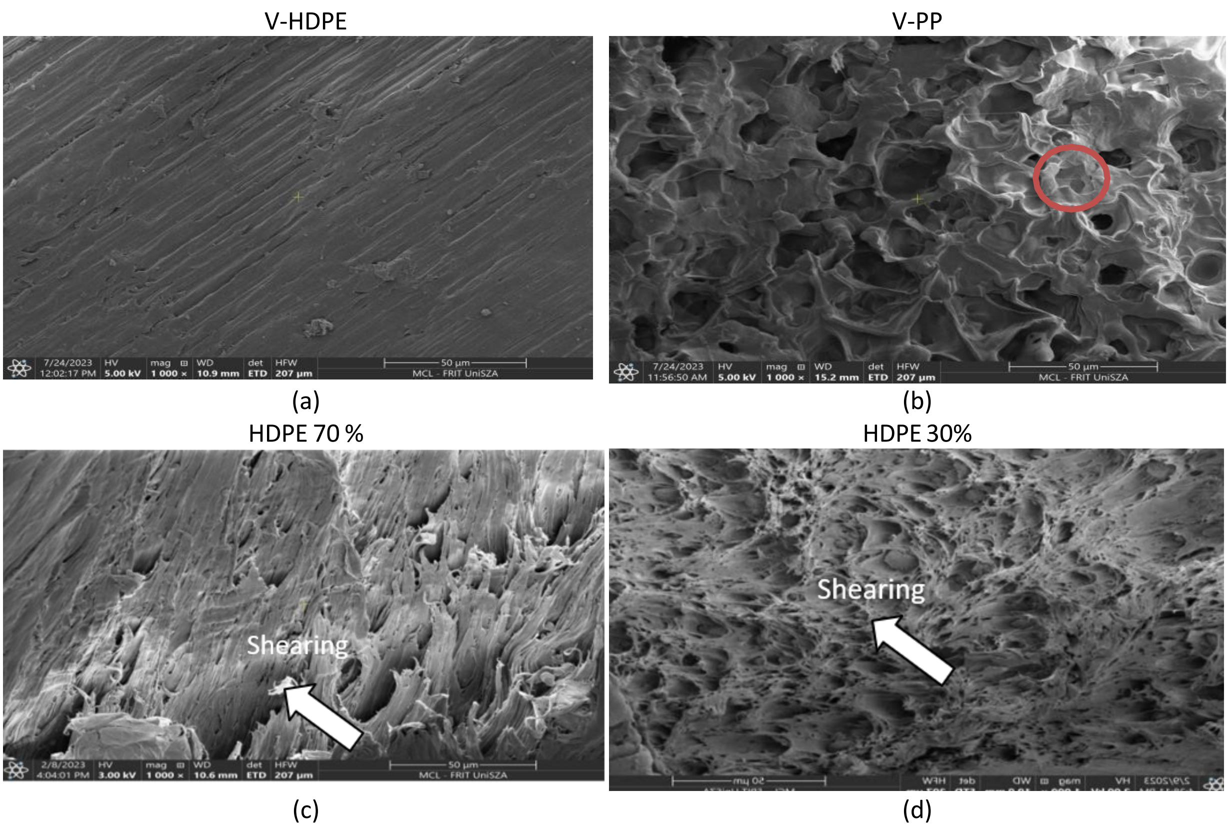
For both blends, the slope of this portion of the curve becomes more gradual as the proportion of RF waste increases. The contaminants or dust that occasionally make their way into mixtures while manufacturing flexible plastics could be the cause [28]. The variations in weight loss and decomposition rates proved that additional substances impacted plastic decomposition was agreed by Majder-Lopatka *et al.,* [29]. Whereas the degree of branching, the presence of impurities, the size of the particles, or the sample's thermal history have additional factors that could have impacted the values as was reported by Yew *et al.,* [30]. Plasticizers, antioxidants, lubricants, colours, light, heat stabilizers, and thermos-stabilizers were the most used additives that affect a material's properties [29]. From another point of view, the different additions of RF percentage do not significantly affect the polymer blends. The most used HDPE/RF blends are preferable for 3D printer filament production due to higher thermostability fracture properties.

3.3 Morphological Characterization

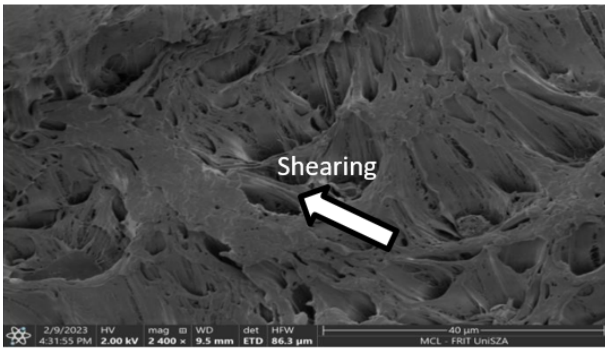
The morphology characteristics were examined on the filament's bulk samples and fracture surface. To characterize the sample, the cross-section morphology and surface area will be scanned under secondary electron mode at magnifications of 100x. Figure 6A to 6G, indicated the morphological structure of the virgin, RF, HDPE/RF, and PP/RF blends. The cross-section of V-PP and PP 30% is relatively smooth and shows similar findings with several researcher [31, 32], and there was no sign of shearing could be observed in Figure 6B and 6F compared to V-HDPE (Figure 6A) and RF (Figure 6G) which show low intensity of shear and brittleness.

From the micrographs, it is observed that the structural fracture of virgin samples, V-PP and V-HDPE, were affected by the composition of RF where the polymer blends become more ductile with the addition of RF. HDPE/RF in Figure 6C and 6D, showed that the morphological structure exhibits ductile fracture mode compared to PP/RF blend samples observed (Figure 6E and 6F) [33]. The Polypropylene based sample such as in Figure 6B and 6F, obtained obvious “core- shell” structure (circle), which characterized a ductile fracture as also reported in Wang *et al.,* [34]. From the observations of Figure 6C and 6E, show that the sample of HDPE 70% seems more ductile with more plastic deformation than PP 70%. The sample PP 30% in Figure 6F, is brittle compared to the sample HDPE 30% (Figure 6D), which seems more ductile with the presence of plastic deformation (arrow) that displays a part of the whiskers that is pulled out of its matrix as the arrow shows. Similar findings were also observed in the study done by Karaagac *et al.,* [35].

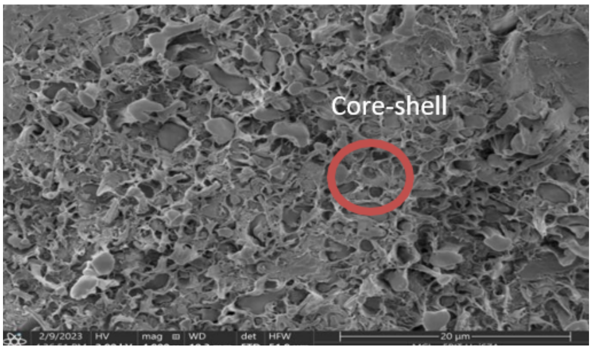
It is also clearly indicated that the trend of changes occurred within both polymer blends, HDPE, and PP, towards the addition of RF, from brittle in virgin polymer becoming ductile at 30% of RF and then at a higher percentage, 70% of RF, turns back to brittle. However, Figure 6G, shows 100% RF had evidence of a brittle fracture behaviour at the ends of the particles where it immersed below the fracture plane, and the interface was relatively flat. Impact strength was decreased because the pullout and bridging effects at the fracture surface were not readily apparent was also supported by Jing *et al.,* [36]. Therefore, it can be concluded that the addition of 30% RF is the best percentage for both polymer blends, where the structure blends appear ductile and is suitable for the 3D printer filament application.



PP 70 %　　PP 30%

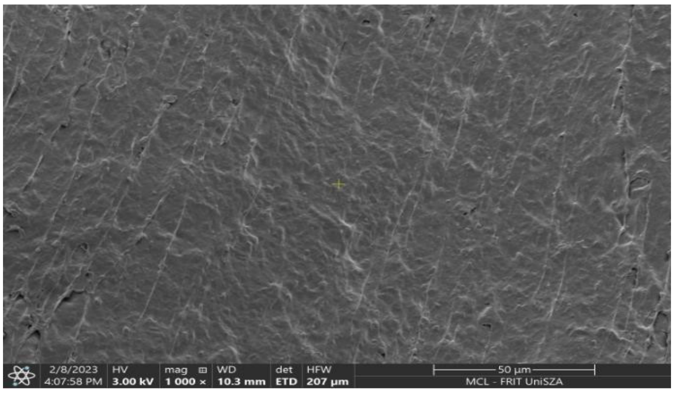


(e)



(f)

RF



(g)

Fig. 6. Morphological properties of virgin, RF, HDPE/RF and PP/RF blends: A) V-HDPE, B) V-PP, C) HDPE 70%, HDPE 30%, E) PP 70%, F) PP 30% and G) RF

The components present in both blends and specific elemental compositions can be compared using energy-dispersive X-ray (EDX) analysis. Table 5 shows the elemental composition in both blends. The RF sample showed numerous chemical elements such as carbon, oxygen, titanium, zinc, aluminium, and copper. As a result, the small amount of titanium detected as the additive in recycled plastic could be derived from Titanium dioxide (TiO_2), which was used as a colorant agent in plastic products [37]. Furthermore, the presence of Zinc refers to (ZnO) commonly used as a filler in plastic production. The small percentage of oxygen in virgin HDPE and PP was due to the ingredients added to the resin during manufacturing as also suggested by Nguyen *et al.,* [38].

Table 5
Elemental composition of HDPE/RF and PP/RF blends

Sample	Composition (wt%)						
	C	O	Ti	Zn	Al	V	Cu
RF	92.6	6.8	0.1	0.1	0.1	-	0.1
HDPE	98.8	1.1	-	-	-	-	-
HDPE 70 / RF 30	94.6	5.4	-	-	-	-	-
HDPE 30 / RF 70	97.6	2.2	-	0.2	-	-	-
PP	92.9	7.0	-	-	-	-	-
PP 70 / RF 30	96.6	3.2	-	0.1	-	-	-
PP 30 / RF 70	93	6.7	0.2	-	-	-	-

Figure 7 refers to the percentages of carbon contents before and after the RF blend. The trend of HDPE/RF shows a decrease in the carbon percentage due to a decrease of RF composition, while RF 70 shows the highest carbon percentage, and the lowest carbon percentage was PP.

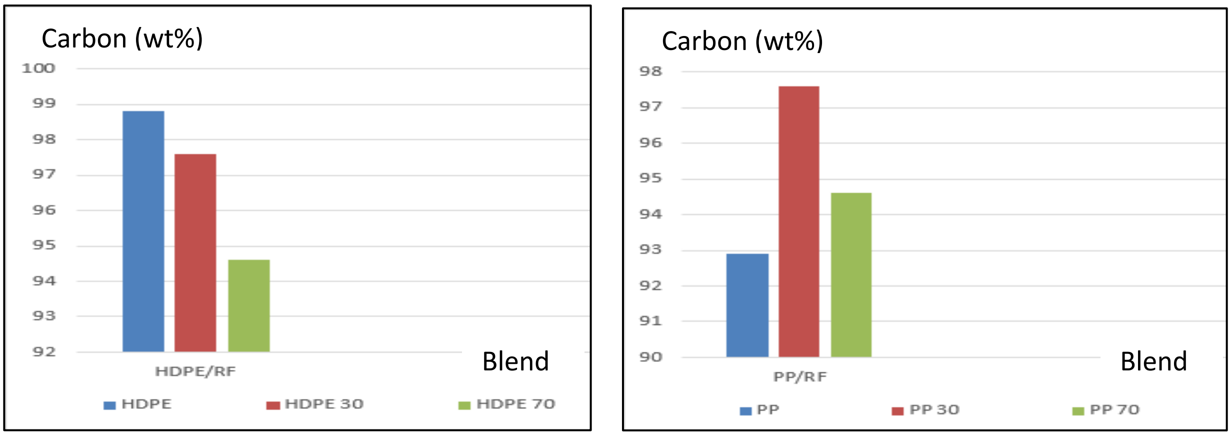


Fig. 7. Carbon percentage in HDPE/RF and PP/RF blend

4. Conclusion

In this study, can evaluate the recyclability of RF blends with HDPE and PP for 3D printer filament production. Hence, a single extruder machine produced recycled flexible plastic from actual waste mixed with virgin HDPE and PP pallets with compositions (100%, 70%, and 30%). From the observation of thermal, structure, and morphological analysis of 3D-printed specimens, the following conclusion has been drawn:

i. In general, the chemical compositions of the two types of blends indicated no differences in chemical bonds among the compositions used in each blend; however, there is a change in peak intensity when different percentages of RF are used in the blends. The action of RF creates a new bond when it blends with V-HDPE and V-PP, such as when there is a newborn addition on the peak875 cm^{-1} of HDPE blends that refers to the low intensity of the (C-H) bending and the addition of lowintense peaks on 875 $cm^{-1,}$ 731 cm^{-1}, and 719 cm^{-1} of PP blends shows of (C=C) bonding with rocking vibrations. It could be the low molecular weight contaminants from RF caused by addictive.
ii. TGA analyses revealed that RF can increase the V-HDPE and V-PP thermal stability when it blends. Variations in weight loss and decomposition rates proved that additional substances in RF impacted plastic's decomposition process. TGA shows the decomposition temperature of the HDPE/RF blends is higher than the PP/RF. The different RF percentages have no significant effect on the polymer blends detected. Therefore, HDPE/RF blend is preferable for 3D printer filament production due to its higher thermostability properties features.
iii. The SEM fracture surface shows that RF, V-PP, and PP 30% show the brittle characteristic rather than V-HDPE, HDPE 30%, PP 70%, and HDPE 70%. From the morphological analysis, it was indicated. That the HDPE/RF blends tend to be more flexible than the PP/RF blends, and the addition of 30% RF is the best percentage for both polymer blends where the structure blends appear ductile and are suitable for the 3D printer filament application.

In conclusion, the RF can be reinforcement material to create a 3D printer filament and future research recommended to justify the output.

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References
[1] Huang, Saimin, Hongchang Wang, Waqas Ahmad, Ayaz Ahmad, Nikolai Ivanovich Vatin, Abdeliazim Mustafa Mohamed, Ahmed Farouk Deifalla, and Imran Mehmood. "Plastic waste management strategies and their environmental aspects: A scientometric analysis and comprehensive review." *International Journal of Environmental Research and Public Health* 19, no. 8 (2022): 4556. https://doi.org/10.3390/ijerph19084556
[2] Popescu, Paul Alexandru, Elisabeta Elena Popa, Amalia Carmen Mitelut, and Mona Elena Popa. "Development of recyclable and biodegradable food packaging materials–Opportunities and risks." *Curr. Trends Nat. Sci* 9 (2020): 142-146. https://doi.org/10.47068/ctns.2020.v9i17.016
[3] Mikula, Katarzyna, Dawid Skrzypczak, Grzegorz Izydorczyk, Jolanta Warchoł, Konstantinos Moustakas, Katarzyna Chojnacka, and Anna Witek-Krowiak. "3D printing filament as a second life of waste plastics—a review." *Environmental Science and Pollution Research* 28 (2021): 12321-12333. https://doi.org/10.1007/s11356-020-10657-8
[4] Jiang, Boyu, Jiming Yu, and Yihang Liu. "The Environmental Impact of Plastic Waste." *Journal of Environmental & Earth Sciences* 2, no. 2 (2020): 26-35. https://doi.org/10.30564/jees.v2i2.2340
[5] Ncube, Lindani Koketso, Albert Uchenna Ude, Enoch Nifise Ogunmuyiwa, Rozli Zulkifli, and Isaac Nongwe Beas. "An overview of plastic waste generation and management in food packaging industries." *Recycling* 6, no. 1 (2021): 12. https://doi.org/10.3390/recycling6010012
[6] United Nations, Department of Economic, Social Affairs, and P. Division, "World Population Prospects Highlights (2019)."
[7] Yusra, AF Ireana, HPS Abdul Khalil, Md Sohrab Hossain, Yalda Davoudpour, A. A. Astimar, A. Zaidon, Rudi Dungani, and AK Mohd Omar. "Characterization of plant nanofiber-reinforced epoxy composites." *BioResources* 10, no. 4 (2015): 8268-8280. https://doi.org/10.15376/biores.10.4.8268-8280
[8] Misran, Mohd Fakhrur Razi, and Mohd Sarhan Othman. "Study on Mechanical Properties of Pla Printed using 3D Printer." *Journal of Advanced Research in Applied Mechanics* 59, no. 1 (2019): 10-18.
[9] Grigore, Mădălina Elena. "Methods of recycling, properties and applications of recycled thermoplastic polymers." *Recycling* 2, no. 4 (2017): 24. https://doi.org/10.3390/recycling2040024
[10] Baechler, Christian, Matthew DeVuono, and Joshua M. Pearce. "Distributed recycling of waste polymer into RepRap feedstock." *Rapid Prototyping Journal* 19, no. 2 (2013): 118-125. https://doi.org/10.1108/13552541311302978
[11] Sulaiman, Nuhu Adam, Zhang Deqiang, Mustapha Mukhtar Usman, and Abdulrahaman S. Ahmad. "Application of CAD/CAE Tools in the Design and Analysis of Plastic Injection Mould." *Journal of Advanced Research Design* 40, no. 1 (2018): 1-8.
[12] Al-Salem, S. M., Paola Lettieri, and Jan Baeyens. "Recycling and recovery routes of plastic solid waste (PSW): A review." *Waste management* 29, no. 10 (2009): 2625-2643. https://doi.org/10.1016/j.wasman.2009.06.004
[13] Xiao, Chunhong, and C. Ernst. "Analyzing Recycled Polyethylene Resin for Polypropylene Contamination Using FT-IR." *Field Application Report* (2011).
[14] Koriem, A., A. M. Ollick, and M. Elhadary. "The effect of artificial weathering and hardening on mechanical properties of HDPE with and without UV stabilizers." *Alexandria Engineering Journal* 60, no. 4 (2021): 4167-4175. https://doi.org/10.1016/j.aej.2021.03.024
[15] Silverstein, R. M., F. X. Webster, and D. J. Kiemle. "Silverstein-spectrometric identification of organic compounds 7th ed." *The State University of New York, College of Environmental Science and Forestry* (2005).
[16] Erbetta, Cynthia DC, Maria Elisa SR Silva, Roberto FS Freitas, and Ricardo G. Sousa. "Accelerated aging and characterization of HDPE pin type insulators (15 kV)." *Polymers and Polymer Composites* 29, no. 9_suppl (2021): S1641-S1648. https://doi.org/10.1177/09673911211047682
[17] Karaagac, Erdal, Mitchell P. Jones, Thomas Koch, and Vasiliki-Maria Archodoulaki. "Polypropylene contamination in post-consumer polyolefin waste: characterisation, consequences and compatibilisation." *Polymers* 13, no. 16 (2021): 2618. https://doi.org/10.3390/polym13162618
[18] Gall, Markus, Paul J. Freudenthaler, Joerg Fischer, and Reinhold W. Lang. "Characterization of composition and structure–property relationships of commercial post-consumer polyethylene and polypropylene recyclates." *Polymers* 13, no. 10 (2021): 1574. https://doi.org/10.3390/polym13101574
[19] Smith, Brian. "The infrared spectra of polymers II: polyethylene." *Spectroscopy* 36, no. 9 (2021): 24-29. https://doi.org/10.56530/spectroscopy.xp7081p7

[20] Prabowo, I., J. Nur Pratama, and Mochamad Chalid. "The effect of modified ijuk fibers to crystallinity of polypropylene composite." In *IOP Conference Series: Materials Science and Engineering*, vol. 223, no. 1, p. 012020. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/223/1/012020

[21] Gall, Markus, Andrea Schweighuber, Wolfgang Buchberger, and Reinhold W. Lang. "Plastic bottle cap recycling—Characterization of recyclate composition and opportunities for design for circularity." *Sustainability* 12, no. 24 (2020): 10378. https://doi.org/10.3390/su122410378

[22] Gall, Markus, Reinhold W. Lang, Joerg Fischer, Ansgar Niehoff, and Steven Schmidt. "Characterization of post-use polyethylene and polypropylene recyclate blends for pipe applications." In *Proceedings of the 19th Plastic Pipes Conference PPXIX, Las Vegas, NV, USA*, pp. 24-26. 2018.

[23] Haryńska, Agnieszka, Helena Janik, Maciej Sienkiewicz, Barbara Mikolaszek, and Justyna Kucińska-Lipka. "PLA–Potato thermoplastic starch filament as a sustainable alternative to the conventional PLA filament: processing, characterization, and FFF 3D printing." *ACS Sustainable Chemistry & Engineering* 9, no. 20 (2021): 6923-6938. https://doi.org/10.1021/acssuschemeng.0c09413

[24] Kakroodi, A. Ramezani, and D. Rodrigue. "Highly filled thermoplastic elastomers from ground tire rubber, maleated polyethylene and high density polyethylene." *Plastics, rubber and composites* 42, no. 3 (2013): 115-122. https://doi.org/10.1179/1743289812Y.0000000042

[25] Techawinyutham, Laongdaw, Jiratti Tengsuthiwat, Rapeeporn Srisuk, Wiroj Techawinyutham, Sanjay Mavinkere Rangappa, and Suchart Siengchin. "Recycled LDPE/PETG blends and HDPE/PETG blends: Mechanical, thermal, and rheological properties." *Journal of Materials Research and Technology* 15 (2021): 2445-2458. https://doi.org/10.1016/j.jmrt.2021.09.052

[26] Yao, Zhitong, Shaoqi Yu, Weiping Su, Weihong Wu, Junhong Tang, and Wei Qi. "Comparative study on the pyrolysis kinetics of polyurethane foam from waste refrigerators." *Waste Management & Research* 38, no. 3 (2020): 271-278. https://doi.org/10.1177/0734242X19877682

[27] HPS, Abdul Khalil, Chaturbhuj K. Saurabh, Mustapha Asniza, Ying Y. Tye, Mohammad R. Nurul Fazita, Muhammad I. Syakir, Hashim M. Fizree *et al.,* "Nanofibrillated cellulose reinforcement in thermoset polymer composites." In *Cellulose-Reinforced Nanofibre Composites*, pp. 1-24. Woodhead Publishing, 2017. https://doi.org/10.1016/B978-0-08-100957-4.00001-2

[28] Hamin, Siti Hajar, Sharifah Hanis Yasmin Sayid Abdullah, Fathurrahman Lananan, Siti Hajar Abdul Hamid, Nor Azman Kasan, Nurul Najidah Mohamed, and Azizah Endut. "Effect of chemical treatment on the structural, thermal, and mechanical properties of sugarcane bagasse as filler for starch-based bioplastic." *Journal of Chemical Technology & Biotechnology* 98, no. 3 (2023): 625-632. https://doi.org/10.1002/jctb.7218

[29] Majder-Łopatka, Małgorzata, Tomasz Węsierski, Artur Ankowski, Kamil Ratajczak, Dominik Duralski, Aleksandra Piechota-Polanczyk, and Andrzej Polanczyk. "Thermal analysis of plastics used in the food industry." *Materials* 15, no. 1 (2021): 248. https://doi.org/10.3390/ma15010248

[30] Yew, Been Seok, Martini Muhamad, S. Bahri Mohamed, and Fwen Hoon Wee. "Effect of alkaline treatment on structural characterisation, thermal degradation and water absorption ability of coir fibre polymer composites." *Sains Malays* 48, no. 3 (2019): 653-659. https://doi.org/10.17576/jsm-2019-4803-19

[31] Yusra, AF Ireana, H. Juahir, NW Nik Ahmad Firdaus, A. H. Bhat, A. Endut, HPS Abdul Khalil, and G. Adiana. "Controlling of green nanocellulose fiber properties produced by chemo-mechanical treatment process via SEM, TEM, AFM and image analyzer characterization." *Journal of Fundamental and Applied Sciences* 10, no. 1S (2018): 1-17.

[32] Razali, Siti Aisyah, Nor Azwadi Che Sidik, and Hasan Koten. "Cellulose nanocrystals: a brief review on properties and general applications." *Journal of Advanced Research Design* 60, no. 1 (2019): 1-15.

[33] Seier, Martina, Sascha Stanic, Thomas Koch, and Vasiliki-Maria Archodoulaki. "Effect of different compatibilization systems on the rheological, mechanical and morphological properties of polypropylene/polystyrene blends." *Polymers* 12, no. 10 (2020): 2335. https://doi.org/10.3390/polym12102335

[34] Wang, Wenzhao, Xiaochao Zhang, Zongyuan Mao, and Weiquan Zhao. "Effects of gamma radiation on the impact strength of polypropylene (PP)/high density polyethylene (HDPE) blends." *Results in Physics* 12 (2019): 2169-2174. https://doi.org/10.1016/j.rinp.2019.02.020

[35] Karaagac, Erdal, Thomas Koch, and Vasiliki-Maria Archodoulaki. "Choosing an effective compatibilizer for a virgin HDPE rich-HDPE/PP model blend." *Polymers* 13, no. 20 (2021): 3567. https://doi.org/10.3390/polym13203567

[36] Jing, Yanwei, Xueying Nai, Li Dang, Donghai Zhu, Yabin Wang, Yaping Dong, and Wu Li. "Reinforcing polypropylene with calcium carbonate of different morphologies and polymorphs." *Science and Engineering of Composite Materials* 25, no. 4 (2018): 745-751. https://doi.org/10.1515/secm-2015-0307

[37] Woo, Hyunjeong, Seung Hyun Kang, Yejin Kwon, Yonghyun Choi, Jiwon Kim, Don-Hyung Ha, Masayoshi Tanaka *et al.,* "Sensitive and specific capture of polystyrene and polypropylene microplastics using engineered peptide biosensors." *RSC advances* 12, no. 13 (2022): 7680-7688. https://doi.org/10.1039/D1RA08701K

[38] Thanh, Nguyen Trung, Nguyen Ba Ngoc, Truong Dinh Tuan, Hoang Ngoc Phuoc, Nguyen Van Huy, and Tran Van Quyen. "Preparation and Properties of Nanocomposite Based on K-153 Epoxy Reinforced T-13 Glass Fiber." *Malaysian Journal on Composites Science & Manufacturing* 10, no. 1 (2023): 1-10. https://doi.org/10.37934/mjcsm.10.1.110