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RESEARCH ARTICLE

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The evaluation of waste engine oil/old newspaper in recycled low density polyethylene composites

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Abstract

The study investigates changes in the mechanical, thermal, morphological and physical properties of recycled low density polyethylene (LDPE) composites made with percentages (10 wt%, 20 wt%, 30 wt.%) of old newspaper fiber (ONF) and waste engine oil (WEO) (1 wt.%). The composites were manufactured by a single screw extruder. Adding WEO up to 20 wt% of ONF had a positive effect on the flexural properties, while the incorporation of WEO up to 10 wt % of ONF showed an affirmative effect on the tensile properties of the composites. The highest flexural strength was achieved in A3 (13.19 MPa) and B3 (12.3 MPa) samples for ONF added composites and ONF/WEO composites, respectively. Adding to the WEO decreased the water absorption values of the recycled low density polyethylene composites. Differential scanning calorimetry analysis showed that the addition of 1% WEO, the crystallinity of the composites decreased to about 30%. In the light of the results, the WEO could be successfully used with old newspaper in a polyethylene matrix.

Highlights

- The highest tensile strength was achieved in the B3 sample (with WEO).
- The highest flexural strength was achieved in the B3 sample (with WEO).
- The highest tensile was obtained from the A3 sample (without WEO).
- The highest flexural strength was obtained from the A3 sample (without WEO).
- The crystallinity of the composites decreased to about 30%.

KEYWORDS

low density polyethylene composite, old newspaper, recycled, waste engine oil

1 | INTRODUCTION

Nowadays, it has become attractive to use natural cellulose fibers instead of synthetic fibers in composite materials due to their environmental properties and low costs. Besides various cellulose fibers, wood flour,[1] sawdust,[2,3] paper mill sludge,[4,5] old newspaper[6–8] and cellulose wastes such as sugar cane,[9] corn cob,[10] straw[11] are used as filling materials in plastic composites. One of the most significant recyclable components of the solid waste stream is old newspaper. It is also a good alternative source for plastic composites due to their wood-like properties.[8]

In general, it is highly concentrated, such as stone mechanical or thermomechanical pulp. About 30% of the old newspaper can consist of kraft or sulfite pulp fibers to improve strength properties. In addition, it can contain starch, filler and dyestuffs for color control, depending on the production flow. It is known that the ash content of old newspaper is between 3% and 12%.[12] The mechanical properties of the composites produced by using 40% of the old newspaper in polypropylene were improved.[13] In another study related to old newspaper fibers the impact strength of old newspaper fiber filled recycled poly(ethylene terephthalate) reinforced composites increased, but their tensile and flexural strengths decreased. It was also observed that the crystallinity value and thermal stability of the composites increased.[14]

Evaluation of waste engine oils as another waste is inevitable in terms of environmental problems. Waste oil needs to be disposed of properly because it may be toxic and contain hazardous materials. High levels of used oil exposure can result in tremors, headaches, and skin rashes. Benzene, hydrocarbons, gasoline, diesel and antifreeze are found in used motor oil. The environment and human health are negatively impacted by the storage of waste engine oils and their direct or indirect discharge into groundwater, surface waters, seas, and soil through drainage systems.[15,16] A mineral oil or any synthetic oil gets contaminated chemically and physically for a certain period of time, especially for lubrication in industry or non-industrial areas, and loses its original characteristic. The oil gets dirty by the breakage of the additives in it, by mixing with dirt, metal frictions, water or chemicals during normal use, and becomes unusable by getting darker in color. If it is used for a long time, it will not perform well enough. The waste oils should never be thrown into the soil and water since it harms the living creatures in the environment due to they have eco-toxic properties and pollute the environment. Heavy metal and chlorine compounds in the waste oils are released into the atmosphere, polluting the air and harming human health. One liter of oil renders 1 million liters of water unusable and 5 million liters of water undrinkable while the same amount of used engine oil renders 800 thousand liters of drinking water unusable.[15,17–19]

In this study, the waste engine oil will be used instead of coupling agents. The interface between non-polar plastics and polar wood flour in wood-plastic composites, which generally consists of a mixture of plastics such as high-density polyethylene or propylene and fillers such as wood flour, enhances with a coupling agent that provides stress transfer when a load is placed on the composite material in between the two phases. They provide the chemical interaction between the polymer and additives. Thus, it improves the adhesion and dispersibility between incompatible materials by positively affecting the mechanical and physical properties of the polymer composite. The coupling agents generally used in the polymer matrix are maleic polyolefins (maleic polypropylene or maleic polyethylene), organic acids or anhydrides.[20,21] Stearic acid, mineral oil and maleic ethylene are also used as couple agents at a rate of about 1% by weight of fiber. The mineral oils absorbed by the fibers prevent the interaction between each fiber and allow the fibers to separate within the polymer.[22] In another study, the flexural strength values of composites produced using waste engine oil, wood flour, and low density polyethylene decreased as the ratio of wood dust increased when the waste engine oil was kept constant at 10%. The composite produced using 10% waste engine oil and 36% wood dust also exhibited the highest flexural strength of 13.69 MPa. The flexural strength of composite produced using 1% waste engine oil and 59% wood dust was also found to be 8.03 MPa. When the usage of waste engine oil is increased from 1% to 5%, the decrease in flexural strength is due to mineral oils forgiven for dilution caused by hydrocarbon. Due to the hydrocarbon component of the waste engine oil, there is a weak interaction with wood dust, therefore, when used in large quantities, they act as a diluent compared to wood dust.[21]

The development of waste-based wood-plastic composites with good physical and mechanical properties will provide effective waste management. However, the impact of the use of waste engine oil in the polymer matrix has not been fully investigated. The mechanical, thermal, physical, and morphological properties of the recycled low density polyethylene composites produced by using waste engine oil and old newspaper fibers were investigated in this study.

2 | MATERIALS AND METHODS

2.1 | Material

The recycled low density polyethylene was supplied by Petkim Petrochemical Company in Izmir, Turkey. The waste diesel engine oil was provided by Renault service in Trabzon, Turkey. The old newspapers used as lignocellulosic material had printed on the same day.

2.2 | Preparation of the old newspaper fibers

The old newspapers were re-fibered in a laboratory type pulper (Pulper) at a temperature of 45–50°C, 8% concentration, and 1% sodium hydroxide in 10 min. The pulps formed after fiberization were dried in the oven, ground in the Willey mill and sieved to the desired mesh sizes.

The reason why the old newspapers were not directly ground is to ensure that the ink and additives were mixed more homogeneously into the fibers. In addition, with such a pre-treatment, fiber cuts were less with grinding made on doughs with a larger surface area and thickness compared to direct dry grinding. The prepared old newspaper fibers were made ready by drying them at 103°C for 24 h.

2.3 | PCBs analysis of WEO

PCBs analysis of WEO was analyzed according to EN 12766-1[23] and EN 12766-2 standard.[24] Metal analysis was determined according to EPA 3051 A[25] and EPA 6020 B[26] standard. The results of this were given in previous study.[27] Table 1 shows PCBs results of WEO. Table 2 indicates waste oil categories. According to heavy metal determination of WEO and PCBs results, it was concluded that the used WEO this study is not in the dangerous category.

2.4 | Composite production

The dried old newspaper fiber, recycled low density polyethylene and waste engine oil were mixed homogeneously in the proportions indicated in Table 3. The mixture was then fed into a single screw extruder. The extruder conditions were set at 100 rpm screw speed, temperatures of 170, 175, 180, and 185°C. Before pelletization, the extruded strands were cooled using a water cooling system. The oven-dried pellets were molded in the hot press with a pressure of 10 MPa and a temperature of 180°C for 3 min. The composites were conditioned in the climate room at 20°C and 65% relative air humidity overnight before testing. The images of the composites manufactured were shown in Figure 1.

2.5 | Determination of mechanical properties

Flexural, tensile and impact tests were performed by the Zwick/Roell Z010 Universal Tester with a 50 kN load cell according to the ASTM D 790 standard,[29] ASTM D 638,[30] and ASTM D 256,[31] respectively. The flexural test was carried out at a constant speed rate of 2 mm/min while

TABLE 1 PCBs results of WEO.

Parameter	Measured value (ppm)
Arsenic	<0.1
Cadmium	<0.1
Crom	<1.5
Lead	<0.1
PCBs (Toplam)	<0.1

TABLE 3 Manufacture design of the composites.

	Composition[a]		
Sample	LDPE (%)	ONF fiber (%)	WEO (%)
LDPE	100	-	-
LDPE-WEO	99	-	1
A1	90	10	-
A2	80	20	-
A3	70	30	-
B1	89	10	1
B2	79	20	1
B3	69	30	1

[a]Values are percentage by weight (wt%).
Abbreviations: LDPE, low density polyethylene; ONF, old newspaper fiber; WEO, waste engine oil.

TABLE 2 Waste oil categories.[28]

	Limit values		
Pollutants	1st category waste oil	2nd category waste oil	3rd category waste oil
Arsenic	<5 ppm	Maximum 5 ppm	>5 ppm
Cadmium	<2 ppm	Maximum 2 ppm	>2 ppm
Crom	<10 ppm	Maximum 10 ppm	>10 ppm
Chloride	Maximum 200 ppm	Maximum 2000 ppm	>2000 ppm
Lead	<100 ppm	Maximum 100 ppm	>100 ppm
Total halogens	Maximum 200 ppm	Maximum 2000 ppm	>2000 ppm
Polychlorinated biphenyls (PCB)	Maximum 10 ppm	Maximum 50 ppm	>50 ppm

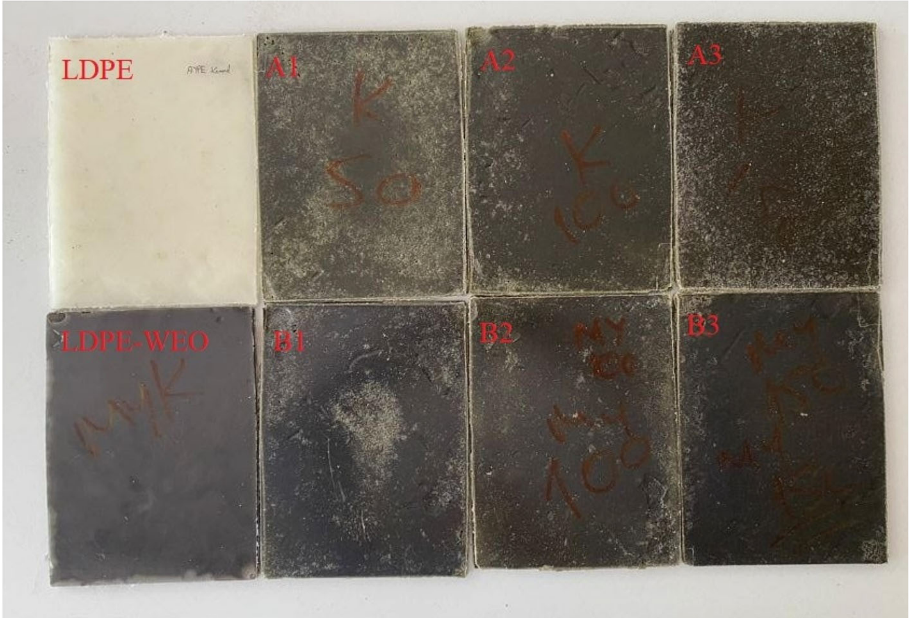

FIGURE 1 The images of the composites manufactured.

the tensile test was also made with a 5 mm/min cross speed using a Zwick/Roell Universal testing machine (Zwick Z050, Germany) which has a load cell capacity of 50 kN. The notches for Izod impact test was made using a notching cutter (Ray-Ran test Equipment Ltd., Polytest, UK). They were tested on an impact testing machine (Zwick, HIT5.5P; Germany). For each group, at least ten samples were measured to obtain average values.

2.6 | Determination of thermal properties

2.6.1 | Differential scanning calorimetry analysis (DSC)

DSC analysis is a method used to detect different energy changes that occur when the product is heated, cooled and kept at the same temperature. Perkin Elmer (Model DSC 8000) device was used for DSC analysis in this study. After the samples (6 ± 0.2 mg) were covered with an aluminum container, they were placed in the device. During the test phase, the temperature value was increased to 250°C by increasing 10°C/min, and the nitrogen gas flow rate was adjusted to 20 mL/min during the test phase. In the analysis phase, the composites were first heated to 250°C and then allowed to cool again. The samples, which were left to cool, were tested by reheating to 250°C after cooling.

It was measured in 3 steps as heating, cooling and reheating under nitrogen gas conditions. The following equation was used to determine the polymer's degree of crystallinity (X_c).[32]

$$X_c(\%) = \left(\frac{\Delta H_m}{\Delta H_0 x W}\right) \times 100 \quad (1)$$

ΔH_m and ΔH_0 denote the heat fusion of composite and 100% crystalline polyethylene, respectively, and W denotes the plastic ratio. In this study, the ΔH_0 value of polyethylene was taken as 293 J/g.

2.6.2 | Thermogravimetric analysis (TGA)

Thermogravimetric analyzes (TGA) of the samples provide important information about the decomposition temperatures of the material. TGA analysis of composites was made with Perkin Elmer (Model STA 6000) test device by using an alumina ceramic crucible under nitrogen. All samples were 4–5 mg in weight. The temperature values were increased from room temperature to 600°C by 10°C/min and the nitrogen gas flow was adjusted to be 20 mL/min. TGA graphs were formed by determining the change in sample weight by measuring the temperature change.

2.7 | FTIR-ATR characterization

The structure of the old newspaper fibers was examined with the attenuated total reflection (ATR) attachment integrated into Fourier transform infrared spectroscopy (FTIR). FTIR measurements of the composites made with the Fourier transform infrared (FTIR-ATR) spectra (Shimadzu IR Prestige-21/Pike Miracle ATR) were performed by averaging 24 scans at a resolution of 16 cm^{-1} in the range of 600–4000 cm^{-1}.

2.8 | Water absorption

The water absorption rate for 50 × 50 × 5 mm specimens was determined in accordance with the ASTM D 1037 standard.[33] The samples were weighed with an accuracy of ±0.01 g. Afterward, the composites were kept in water at 23 ± 2°C during the experiment by keeping them 25 mm below the water's surface. The measurements were made periodically at 1, 2, 3, 4, 5, 6, 7, and 8 weeks, 3 and 5 months. Their surfaces were dried and then their weights were calculated based on the initial oven dry weight, respectively. For each group, ten replicates were tested.

2.9 | Morphological properties

The morphological properties of the composites were examined by scanning electron microscopy (SEM). The samples were analyzed under vacuum using a scanning electron microscope (ZEISS EVO LS 10, Carl Zeiss NTS GmbH, Germany). Before the analysis, the samples were gold coated by the sputtering technique. Images were obtained from 10 kV with 500 × SEM micrograph magnifications.

2.10 | Statistical analysis

Statistical analyzes of the results of the mechanical tests were made using the SPSS 21.0 statistical package software program. One way ANOVA test was carried out to determine whether there are significant differences between the mechanical properties of the composite types.

3 | RESULTS AND DISCUSSION

3.1 | Characterization of composite materials

FTIR-ATR spectra of composites containing old newspaper fiber and waste engine oil / the old newspaper fiber is shown in Figure 1. In all spectra, CH_2 asymmetrical C-H tension in the 2917 cm^{-1} band, CH_2 symmetrical C-H tension in the 2852 cm^{-1} band, umbrella mode of CH_3 in the 1377 cm^{-1} band and CH_2 oscillation peak in the 718 cm^{-1} band are observed, originating from low density polyethylene. The most important difference between low density and high density polyethylene is the

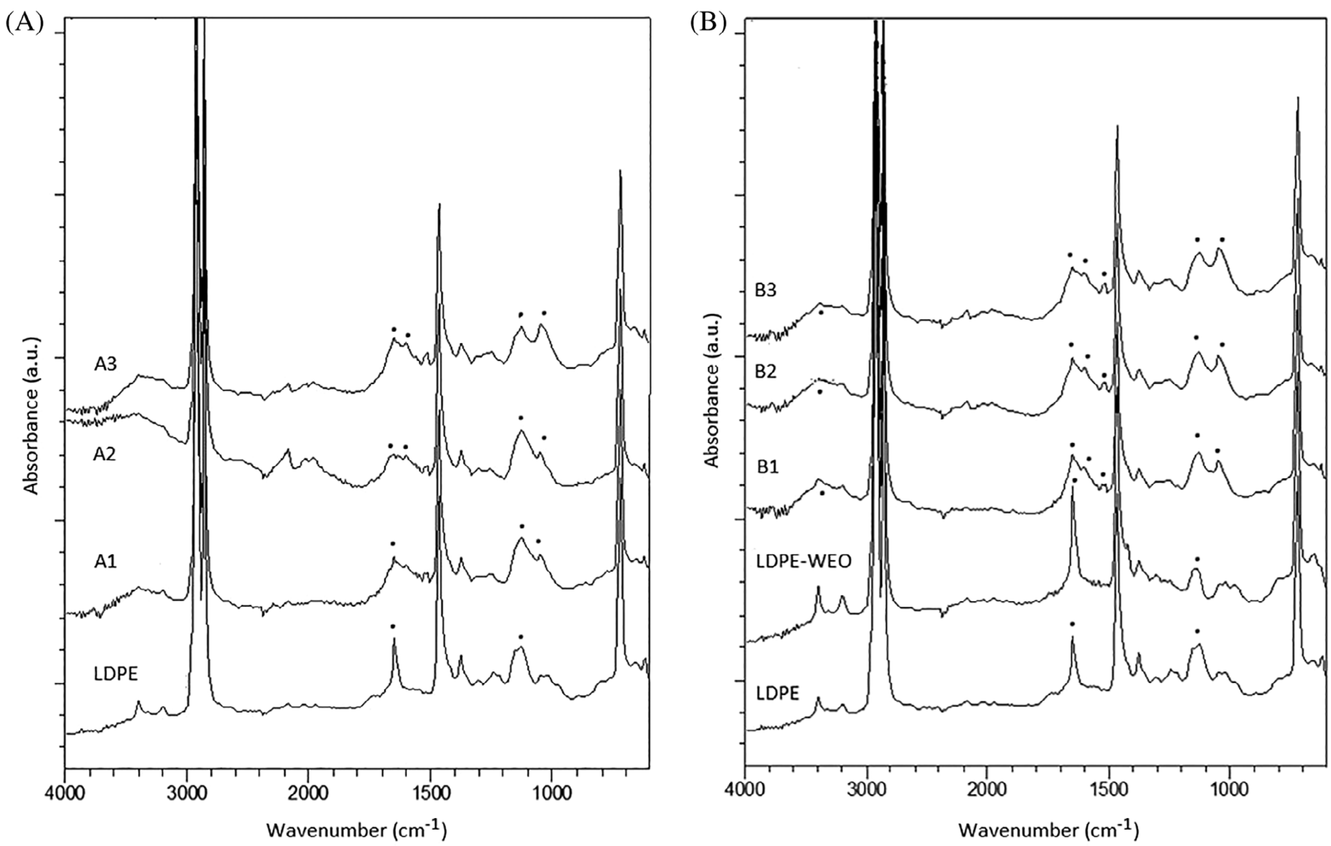

FIGURE 2 FTIR-ATR spectra of composites; (A) old newspaper fiber and LDPE; (B) old newspaper fiber, WEO and LDPE.

TABLE 4 TGA results of LDPE and ONF/WEO reinforced composites.

	First degradation step				Second degradation step				
	Onset temperature (°C)	Inflection point temperature (°C)	Endset temperature (°C)	ΔY (%)	Onset temperature (°C)	Inflection point temperature (°C)	Endset temperature (°C)	ΔY (%)	Residual at 895°C (%)
ONF	321.00	374.82	392.14	65.58	-	-	-	-	13.43
LDPE	-	-	-	-	458.95	**476.80**	493.60	99	0.07
A1	332.57	**356.21**	361.42	4.40	463.60	**485.12**	499.18	90.85	0.09
A2	330.34	**346.81**	366.81	7.85	466.43	**486.70**	499.06	82.81	0.01
A3	349.90	**359.42**	363.14	10	464.16	**485.38**	500.89	79.02	0.28
B1	336.49	**359.11**	370.04	5.75	464.98	**485.61**	498.29	88.14	0.28
B2	332.45	**370.69**	379.78	11.21	465.89	**488.56**	499.67	79.25	0.18
B3	361.21	**386.46**	387.43	12.14	489.09	**499.28**	500.10	70.85	0.96

Note: ΔY: the percent weight loss of sample between the designated temperatures. The bold values indicates Inflection point temperature.

peak around 1377 cm^{-1}. This methylene peak is not observed in high density polyethylene due to higher crystallinity.[34]

In Figure 2, by increasing the fiber content added to the polymer matrix, peak formation was observed in the approximately 1044 cm^{-1} band[35] due to the C-O tension of the cellulose. Similarly, in composites containing old newspaper, the peak formation due to the C-O-C symmetrical tension of cellulose[35] is observed in the band of approximately 1120 cm^{-1}. Due to the lignin content of the old newspaper, the peak density also increased in 1510 and 1650 cm^{-1} bands with the increase in fiber content. These bands are due to the stretch vibration of the double bonds in the aromatic ring of lignin[36–39] and the C=O stretching vibration of the lignin conjugated carbonyl structures originates.[39] The presence of long chain alkyl groups in the WEO is indicated by a strong peak at 1459 cm^{-1}.[21]

3.2 | Thermal properties of composite materials

TGA curves of old newspaper-reinforced low-density polyethylene (LDPE) composites and old newspaper-low-density polyethylene composites reinforced with WEO are shown in Table 4 and Figure 3.

In Figure 3B–D the derivative curves of the mass changes of the composite plates are seen in the same order (DTGA). In order to more effectively examine the change in the mass of the samples depending on the temperature, it would be more useful to examine the two degradation steps in parts according to the temperatures. Figure 3C shows the DTGA curves of the samples for the first degradation step in the temperature range of 200–400°C. The first degradation step is related to the old newspaper fiber, and it is seen from the graphs that for the samples without engine oil, they peak at 373, 373 and 374°C for 10%, 20% and 30% fiber ratios, respectively. In the samples containing 1% waste engine oil, the peak temperatures for the same ratios are seen as 378, 376 and 375°C, respectively.

The calculated inflection point temperatures were found to be 356, 345 and 359°C for the composites containing 10%, 20% and 30% ONF, respectively. For the first step, and 359°C for the same fiber ratios with the addition of 1% WEO calculated as 370 and 386°C. According to both results, it is concluded that the turning point temperature of the first degradation step increased with the addition of 1% WEO. The reason for this is that WEO increases the lubricating effect and thermal resistance.

Figure 3D shows the DTGA curves of the second degradation steps of the composites. The second degradation step is associated with the degradation of low density polyethylene. However, it is affected by the filler added to the composite product. While the DTGA peak was formed at 481°C in composites where LDPE was used 100%, it increased to 485°C with the addition of 10% fiber. Temperatures of 487 and 486°C were determined for 20% and 30% fiber ratios, respectively. No significant change was observed in the peak temperatures with the addition of 1% WEO to the composite composition. Similar results are also seen at the inflection point temperatures calculated from the degradation steps by means of the software. While the inflection point temperature of LDPE was 494°C, the inflection point temperature increased to 499°C with 10% ONF. The inflection point temperature for the WEO additive and other proportions of fibers did not change much and was measured between 498 and 501°C. The degradation temperature increases with increasing the fiber content.[40]

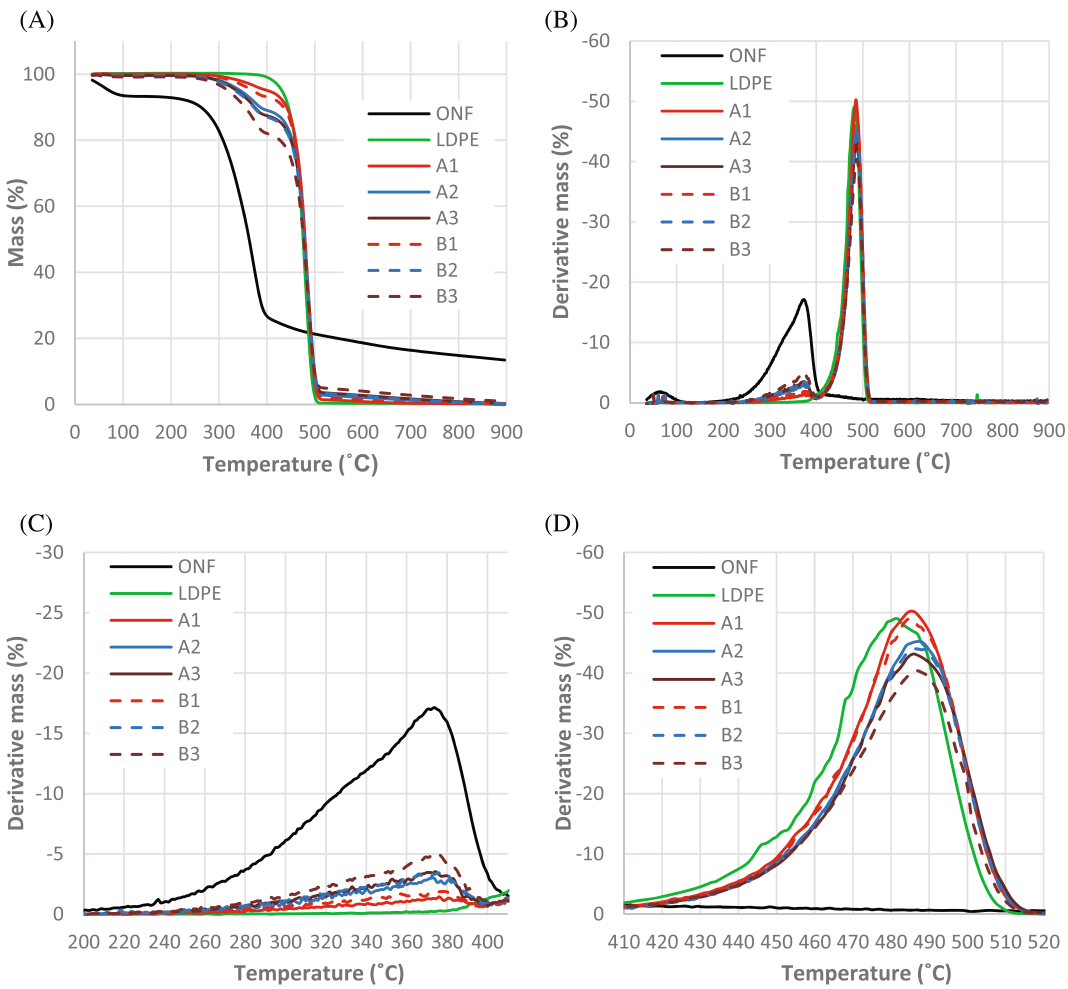

FIGURE 3 The thermogravimetric analysis (TGA) results of LDPE and ONF/WEO reinforced composites (A: TGA curves, B: derivatives of TGA curves, C: first degradation peak, D: second degradation peak).

TABLE 5 DSC results of LDPE and ONF/WEO reinforced composites.

	T_c (°C)	Peak height cold (mW)	ΔH_c (J/g)	T_m (°C)	Peak height melt (mW)	ΔH_m (J/g)	X_c (%)
LDPE	91.97	−23.5934	−75.3646	111.56	14.5386	96.0860	32.79
LDPE-WEO	92.41	−30.0348	−82.1809	110.15	14.7382	104.6851	30.47
A1	94.00	−26.6727	−74.1850	110.60	14.4494	96.2456	36.50
A2	94.28	−21.0256	−63.1515	110.89	12.4132	82.7134	35.29
A3	94.20	−21.0894	−61.3262	110.74	12.4573	78.7403	38.39
B1	94.76	−21.8955	−69.3362	110.01	12.2272	84.8745	32.55
B2	94.85	−19.0783	−62.3267	110.48	11.4814	73.0420	31.56
B3	95.33	−15.2990	−54.5978	109.99	9.2967	61.0119	30.18

Note: T_c: crystallization temperature; ΔH_c: enthalpy of crystallization; T_m: melting point; ΔH_m: enthalpy of melting; X_c: crystallinity.

Table 5 contains the data of the DSC measurement of the samples. Figure 4. shows the DSC curves of the samples. When the results are examined, it is seen that the melting temperature decreased by about 1°C with the addition of WEO for all samples. Similarly, an increase of 1°C was observed in the crystallization temperature with the addition of engine oil. As can be seen from Table 3, the peak height and entalphy decreased with increasing amount of fiber added to LDPE during both heating and crystallization. In addition, it is seen in Figure 4 that the peak height

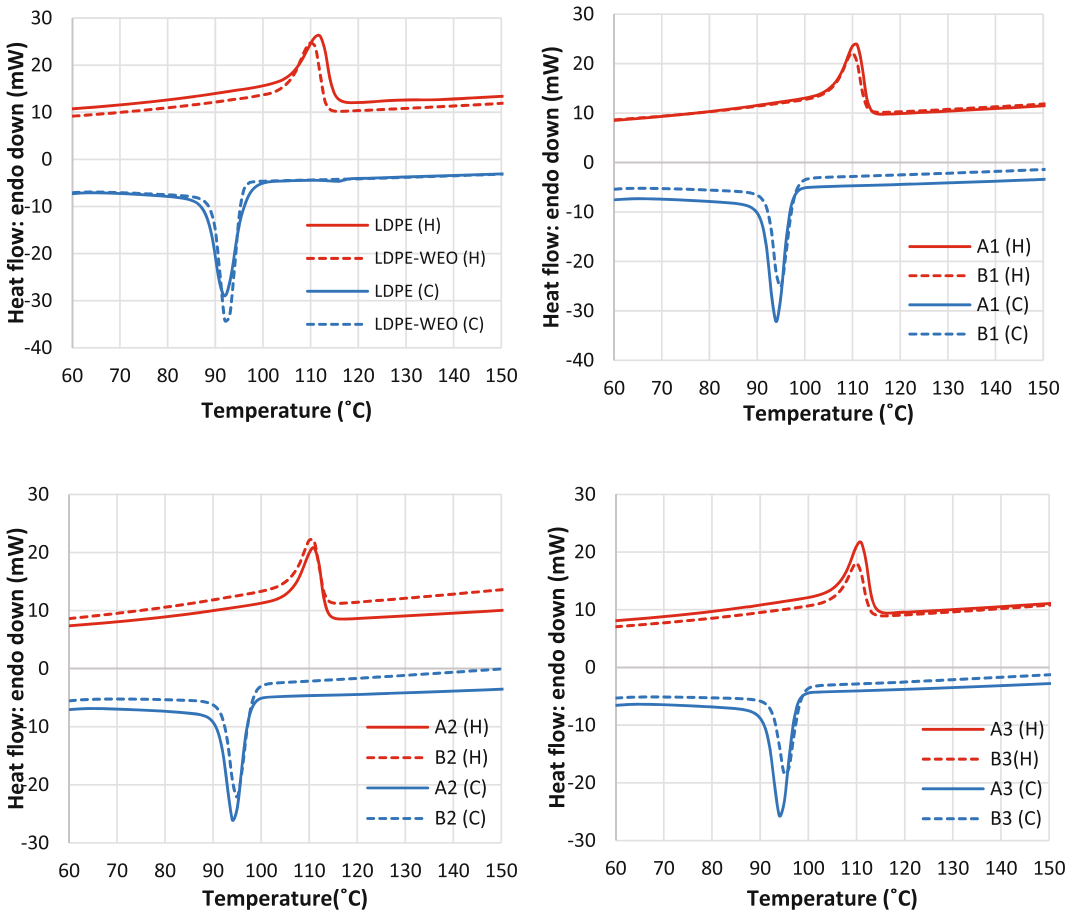

FIGURE 4 DSC curves of samples (H: heat, C: cold).

and entalphy decrease with 1% WEO added to the composite. As seen in Table 3, when only the WEO was added to LDPE, the crystallinity of LDPE decreased by 2%. On the other hand, when 10%, 20% and 30% of old newspaper fiber was added to LDPE, respectively, the crystallinity increased from 32.79% to 36.50%, 35.29% and 38.39%. This situation can be explained by the heterogeneous nucleation of filler. Nucleation can be defined as the formation of embryonic crystallites of critical sizes that are stable at a given temperature and can initiate an increase in crystallite size.[41] With the addition of 1% WEO in addition to the old newspaper fiber to LDPE, the crystallinity decreased to 30%–32%. According to these results, it is understood that the addition of the WEO prevents the nucleatic effect of old newspaper fiber.

3.3 | Mechanical properties of composites

Table 6 shows the mechanical properties of ONF/WEO reinforced composites. The minimum flexural strength value was obtained from the A1 sample (7.56 MPa) while the highest was observed in the A3 sample (13.19 MPa). The values of flexural strength increased as the ratio of old newspaper fiber increased for all composite panels. The usage of waste engine oil improved the flexural strength value of composites. This positive effect is thought to be due to the engine oil acting as a mismatch remover. The increase can arise from an increase in aliphatic organic acids in the composites, resulting in an increase in the coupling effect. The results obtained in the study are compatible with the study in the literature.[21]

The values of the flexural modulus of elasticity of the composites show a similar trend as to the values of flexural strength of these composites. Adding old newspaper fiber as a filler in the polymer matrix increased the flexural modulus of elasticity in both old newspaper fiber added groups and old newspaper fiber/WEO added groups. The highest value of the flexural modulus of elasticity was obtained from the A3 sample had 761.14 MPa. Flexural strength of 6.9 MPa (1000 psi) and flexural modulus of 340 MPa (50,000 psi) are required by the ASTM D 6662[42] standard for polyolefin-based plastic lumber decking boards. In this study, flexural strength values of thermoplastic

TABLE 6 Mechanical properties of LDPE and ONF/WEO reinforced composites.

Samples	Flexural strength (MPa)	Flexural modulus of elasticity (MPa)	Tensile strength (MPa)	Tensile modulus of elasticity (MPa)	Impact resistance (J/m)
LDPE	6.46e*	221.86f	8.93a	728.86e	47.20a
LDPE-WEO	6.02e	200.29f	9.01a	742e	49.78a
A1	7.56d	296.14e	4.96d	632.57f	15.20b
A2	9.38c	416.43c	7.25b	1107.71c	10.62b
A3	13.19a	761.14a	7.25b	1428.57a	7.57b
B1	7.96d	342d	6.79bc	897d	13.21b
B2	9.45c	451.57c	6.16c	956.57d	10.38b
B3	12.3b	706.86b	7.05b	1278.57b	6.84b

*Different letters indicate statistically significant differences between the groups.

composites (7.56–13.19 MPa) and flexural modulus values (342–761.14 MPa) were over the requirement by the standard except for A1 sample.

The tensile strength values of the composites varied between 4.96 and 7.25 MPa. Even though the tensile strength of all composites was decreased as compared to LDPE and LDPE/WEO composite types, with the exception of the B2 and B3 samples, adding to waste engine oil increased the tensile strength value of composites. The addition of old newspaper fibers improved the tensile strength of the composites up to 20% and 30% wt. When the old newspaper fiber was also used above 10% for composites with waste engine oil, the tensile strength values dramatically decreased. The values of tensile modulus of elasticity of composites ranged from 632.57 to 1428.57 MPa. When the values of tensile modulus of elasticity of old newspaper reinforced composites were higher than that of old newspaper fiber and WEO added composites except for the addition of 10% old newspaper fiber.

The minimum value for impact strength was obtained from the B3 sample (6.84 J/m) whereas the maximum value for impact strength was achieved in the A1 sample (15.20 J/m). In contrast to other mechanical properties, the impact strength of old newspaper fibers added composites was reduced to 7.57 J/m due to the composites' increasing brittleness. When the filler loading is increased, the material changes from ductile to brittle, which lowers the impact strength of the composites. This result also was supported by the previous studies.[43–45] The general effect on the impact strength of the addition of WEO to old newspaper fiber reinforced composites was similar to those of old newspaper fiber reinforced composites. However, the impact strength of old newspaper fiber reinforced composites was also influenced negatively by the incorporation of WEO.

3.4 | Water absorption of composites

The water absorption rates of LDPE/WEO, and ONF/WEO reinforced composites are given in Figure 5. The water absorption rates of the composites with the old newspaper fiber addition were higher depending on the time compared to LDPE and LDPE/WEO samples. The water absorption rates of WEO added composites gave better results compared to those without WEO composites. The lowest water absorption rate was obtained from a composite with 20% of old newspaper fiber and 1% WEO. Due to the likely encapsulated wood core with plastic shell microstructure of the composite, the improved dispersion of the plastics within the composites as a result of the additives' good coupling effect in the WEO will ensure a loss of interface for water molecules. A similar trend was observed in another study.[21]

3.5 | SEM analysis of composites

The SEM micrographs of the control sample produced with recycled low density polyethylene, the A2 sample (with 20% ONF), and the B2 sample (20% ONF/1% WEO) are shown in Figure 6. The SEM images show that WEO added composites resulted in better dispersion into polymer matrix as discussed previously in the mechanical properties. The coupling effect of the organic acids, which results in stronger interaction (chemisorption) as waste oil content increases, more than makes up for the dilution effect, increasing the mechanical property of the WPC. Some gaps in the polymer matrix decreased and composites of the ONF with the addition of 1% of WEO showed a more homogeneous distribution compared to those without WEO in the polymer matrix. The

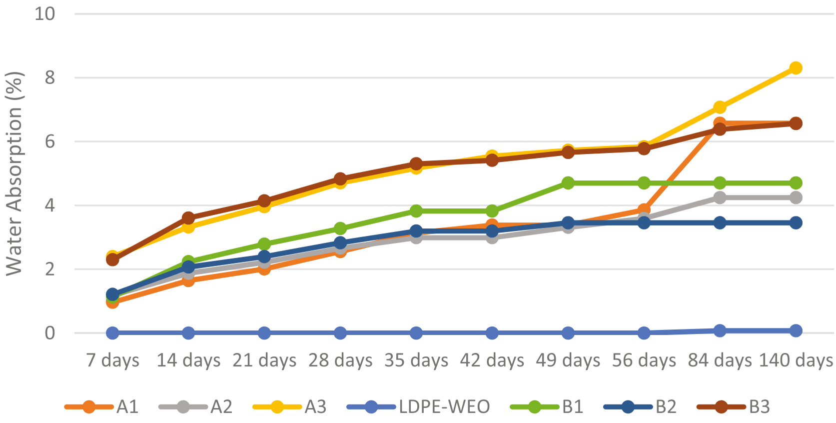

FIGURE 5 The water absorption results of LDPE/WEO and ONF/WEO reinforced composites.

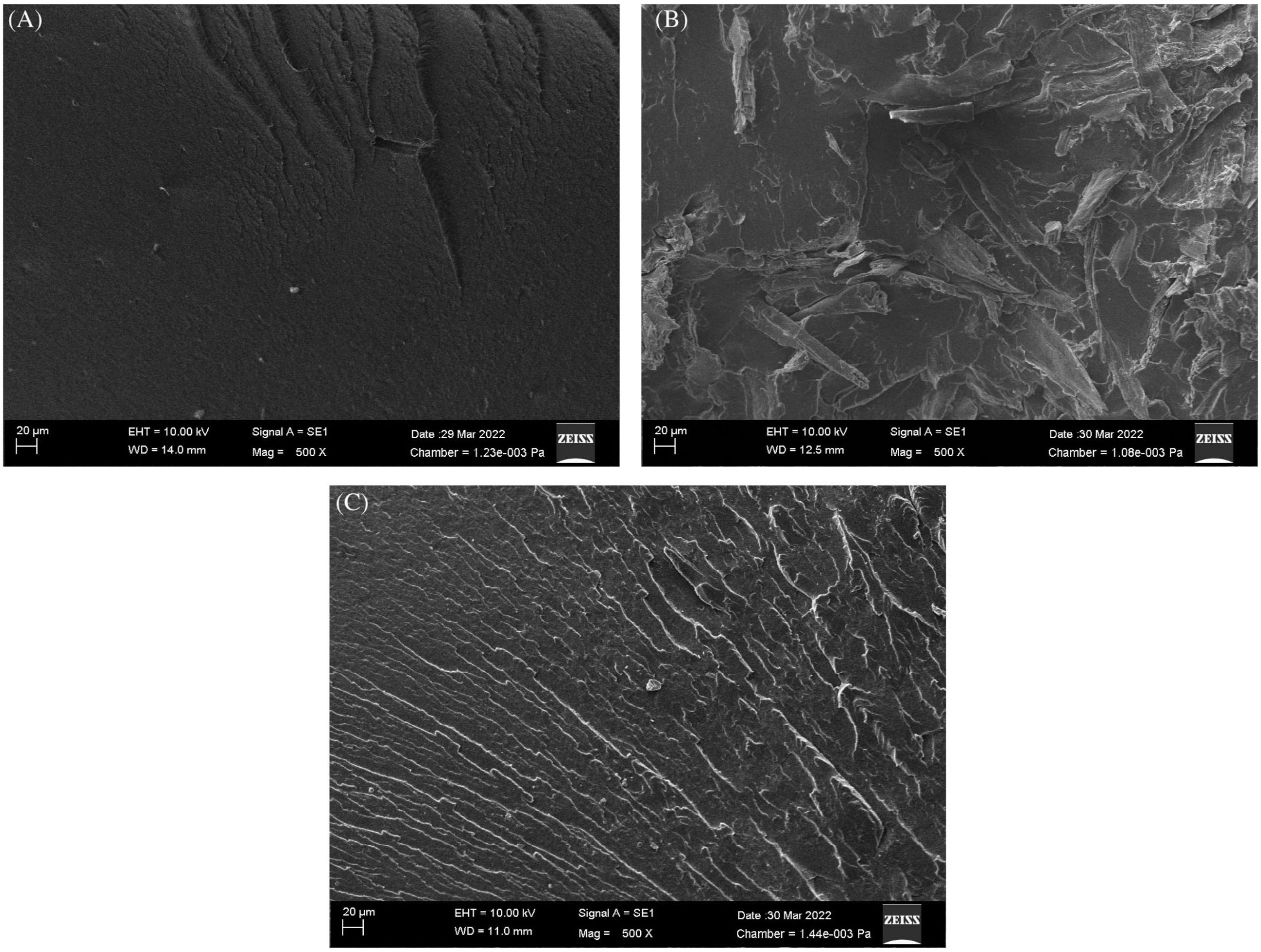

FIGURE 6 SEM image of composites; (A) LDPE, (B) the A2 sample (with 20% ONF addition), (C) the B2 sample (20% ONF/WEO). [Correction added on 31 August 2023, after initial online publication: The correct version of part label (B) in Figure 6 has been replaced.]

reason can be related to the fact that there is a positive correlation between an increase in aliphatic organic acids and mechanical properties. A similar result was observed in the literature. When used WEO as a coupling agent some pullouts and voids were not observed in polymer matrix reinforced wood dust compared to those were without the addition of waste oil.[21]

4 | CONCLUSION

The results revealed that the highest flexural strength was achieved in A3 (13.19 MPa) and B3 (12.3 MPa) samples for ONF added composites and ONF/WEO composites, respectively. The flexural properties of the composites improved when the WEO was used. Whilst the tensile properties of the composites increased up to 10 wt% of ONF except for impact strength depending on enhancing compatibility between the WEO and polymer by increasing the fibrillation of the old newspaper fiber. The results of the mechanical properties are consistent with the SEM observation. The SEM micrographs also showed that the addition of waste engine oil increases the interfacial adhesion between the reinforcement and polymer matrix. Old newspaper fiber and 1% WEO added to LDPE caused the crystallinity to drop to 30%–32%. These findings indicate that the nucleatic effect of old newspaper fiber is prevented by the presence of waste engine oil. Moreover, the addition of 1% WEO increased the turning point temperature of the first degradation step the fact that was which increased the lubricating effect and thermal resistance. In addition, the results show that adding WEO also showed an affirmative effect on the physical properties of the composites.

In conclusion, this work showed that the waste engine oil and old newspaper fiber had the potential into the polyethylene matrix. It was also concluded that the use of both together may be appropriate for solving the waste problem.

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DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

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