JURNAL SAINS MATERI INDONESIA (JUSAMI)
ISSN: 1411-1098 (print), 2614-087X (online)
VOL. 26, ISSUE 2 2025
DOI: https://doi.org/10.55981/jsmi.4963

ORIGINAL ARTICLE

Powder Coating Waste Utilisation as a Filler in High-Density Polyethylene (HDPE) Coupled with PP-g-MA

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ABSTRACT – The powder coating process in the industry typically generates waste during the curing process. This non-recyclable and hazardous powder-coating waste is utilized as filler material in this research. Polyester was employed as filler in the high-density polyethylene (HDPE) matrix composite. The study investigated the impact of polyester composition at 20%, 30%, and 40%, with 5% of polypropylene grafted maleic anhydrate (PP-g-MA) coupling agent addition. To assess the effect as a coupling agent, 0%, 2%, 5%, and 10% of PP-g-MA were added to the composite with a matrix-filler ratio of 70:30. Mixing was conducted using the hot melt mixing method at 180°C and mixing speed 60 rpm, with duration 9 minutes. The characterization and tests include the measurements of surface tension using scanning electron microscope (SEM), Fourier-transform infrared (FTIR) spectroscopy, thermogravimetry analysis (TGA), differential scanning calorimetry (DSC), and micro-tensile tests. The results indicate that polyester and PP-g-MA composition decreases the thermal properties of the composite. However, increasing the filler addition by up to 30% and PP-g-MA addition by up to 5% enhances the thermal properties. The tensile strength and stiffness of the composite with polyester filler and PP-g-MA are higher than pure HDPE. These are achieved with the addition of polyester filler at 20% and a coupling agent composition of PP-g-MA at 5%.

ARTICLE HISTORY
Received: 12 May 2024
Revised: 19 Jun 2024
Accepted: 25 Jul 2024

KEYWORDS
Composite
Coupling agent
Polyester
Powder coating

INTRODUCTION

Polymer is one of the materials that is widely used in everyday life in society. The polymer has advantages compared to other materials, including lightweight, flexible, corrosion resistant, easy to produce, and low cost [1]. One of the utilizations of polymer is in the powder coating industry. In the industrial sector, powder coatings coat the surfaces of various materials such as polymers, woods, and metals. The biggest utilization of powder is for coating metals, with a production reach of 4 million tons per year [2]. Powder coating provides a thick, substantial layer that offers excellent durability, resistance to wear and rust, and a more comfortable grip.

Depending on the type of resin and hardener contained, there are two types of powder coating: thermosetting and thermoplastic powder coating [3]. Thermosetting powder coatings usually contain a resin that will harden when exposed to elevated temperatures due to the curing process initiated by the crosslinking agent. The hard coating formed by thermosetting powder coatings is permanent and unable to be remelted and reshaped. Meanwhile, thermoplastic powder coatings will not harden when exposed to heat since there is no chemical reaction during the curing process. This resulted in the coatings being able to be reshaped and reapplied again [4]. The initial stage of the powder coating process is the mixing process of the materials, such as resin, curing agent, filler, and pigment. The mixing process is followed by extrusion, crushing, and screening to gain powder from the coating process, which is then kept at room temperature. The application of the powder coating process depends on the type of powder coatings. Thermosetting powder coatings are applied using the electrostatic spraying method, while thermoplastic powder coatings are applied using the fluidized bed dipping method. The process is followed by heating and curing the powder [4].

In its application, the powder coating process can occur imperfectly and produces waste in the form of powder through a curing process. Remanufacturing the waste powder for reuse by reinforcing the powder waste with pigments might be a promised solution. However, this process is highly costly, and much more loss occurs during application [5]. Thermoset materials also cannot be recycled. Therefore, this waste in powder form is considered a hazardous and toxic material. This waste can pollute the environment and damage the health of living creatures. Recently, some innovative recycling techniques have been developed using powder coating wastes as filler material in the composite [6]. Previous work has been studied in the utilization of powder coating waste. Powder-coating waste is used as a binder in making wood-based panels and as a filler for recycled high-density polyethylene (HDPE)-based composites [7]. Kismet et al. (2020) investigated the effects of powder coating waste

***CORRESPONDING AUTHOR** | S. D. Ariantika | shinta.dewi23@ui.ac.id using three different thermosetting as fillers on acetal copolymers [2]. They suggest that insufficient homogeneity and void formation in the specimen are the key factors in the tensile strength reduction. Kismet & Dogan (2021), using powder coating waste from the electrostatic spray method, which had been hydrolyzed as a filler for low-density polyethylene (LDPE), a composite was produced with a significant increase in mechanical properties. They found that the binding mechanism of the matrix and filler in the composite is not strong. The voids between the matrix and the filler and the poor distribution of the filler on the matrix indicate that homogeneity is not sufficiently achieved [3].

This research used polyester powder coating waste in the fluidized bed method as filler for HDPE Matrix composite. Polyester resin has advantages over other resins, such as high gloss, good flow, and good decoration. HDPE has flexible properties with high density and scratch resistance [8]. HDPE is one type of polymer widely used in many industrial applications, but this material comes with several limitations [9]. Polyester waste powder can be developed as a filler for HDPE matrix composite to improve its properties. However, HDPE has hydrophobic properties that tend to be non-polar, and polyester waste powder has hydrophilic properties that tend to be more polar. These contrast properties are the major problem for the mixing process. Therefore, it is necessary to add another substance that functions as a coupling agent, such as polypropylene-grafted maleic anhydrate (PP-g-MA), as a coupling agent.

This research aims to investigate the effect of polyester composition from powder coating waste and the coupling agent PP-g-MA addition on the morphology, thermal, and mechanical properties of HDPE matrix composites.

EXPERIMENTAL METHOD

Materials and Instruments

The virgin pellet of high-density polyethylene (HDPE) used is obtained from PT Chandra Asri Petrochemical Tbk Indonesia, with the trademark of Asrene® UB5502H. The thermoset waste powder used as filler is a type of polyester. HDPE matrix and polyester were weighted, and polyester was varied by weight percentage ratio variations. The variation of polyester composition is presented in Table 1.

Table 1. Composition of polyester in composite

Sample Code	Materials		
	HDPE (wt%)	Polyester (wt%)	PP-g-MA (wt%)
PE0	100	0	0
P1	80	20	5
P2	70	30	5
P3	60	40	5

To study the effect of polypropylene grafted maleic anhydrate (PP-g-MA) as a coupling agent, PP-g-MA was added with the variation of weight percentage of 30% polyester and 70% HDPE. The composition was chosen since it is the optimum composition for the composite. The composite with 30% filler composition has the lowest transmission percentage. When the filler composition increases to 40%, there is an increase in the transmission percentage, which means a decrease in the number of hydrogen bonds. The variation of PP-g-MA composition is listed in Table 2.

Table 2. Composition of PP-g-MA in the composite

Sample Code	Materials		
	HDPE (wt%)	Polyester (wt%)	PP-g-MA (wt%)
P4	70	30	0
P5	70	30	2
P2	70	30	5
P6	70	30	10

Method and Procedure

The composite was prepared using the hot melt mixing method. The HDPE was first put in the Rheomix HAAKE Polydrive machine for 2–3 minutes, followed by polyester filler and PP-g-MA coupling agent. During the mixing process, the temperature was set to 180°C with the stirrer mixing speed of 60 rpm, and the total mixing time was 9 minutes. The composite was then processed using the hot press machine with a temperature of 175°C and a pressure of 4 MPa for 15 minutes.

All the samples were characterized by Fourier-transform infrared (FTIR) to determine the functional groups in the sample and the bonds formed. The composite was dipped in liquid nitrogen to obtain a fracture in a brittle condition. The morphology of the transverse fracture surface of the composite was observed using a scanning electron microscope (SEM). The thermal properties of the composite were then analyzed by simultaneous thermal analysis (STA) characterization, which consists of thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). The test was carried out at a temperature of 500°C with a temperature increase rate of 10°C/min. The observed thermal properties are based on the influence of the composition and type of filler as well as the composition of the coupling agent in the composite. Micro tensile testing was carried out to obtain tensile strength values of the samples. The reference for the test is the ASTM D 638 Type IV standard, with a specimen thickness of 2 mm (ASTM International, 2014).

RESULT AND DISCUSSION

Morphology Analysis

Effect of the Filler Composition

The scanning electron microscope (SEM) analysis of the specimen with 30% and 40% filler compositions is given in Figure 1. Figure 1 shows the distribution of white particles in the form of filler. On the fracture surface, there are voids in the composite, which indicate the imperfection of the hot melt mixing process. Compared with the composite containing 30% filler, the composite with 40% showed poorer homogeneity and more visible voids. As the filler composition in the composite increases, the number of pores in the composite also increases. The formation of voids or pores indicates that the matrix and filler do not form a strong enough bond. This trend is supported by tensile test data results, where the increasing filler composition in the composite will decrease the tensile strength value of the composite. The formation of voids or pores in the specimen reduces mechanical strength because cracks could propagate more easily through areas containing voids or pores [10].

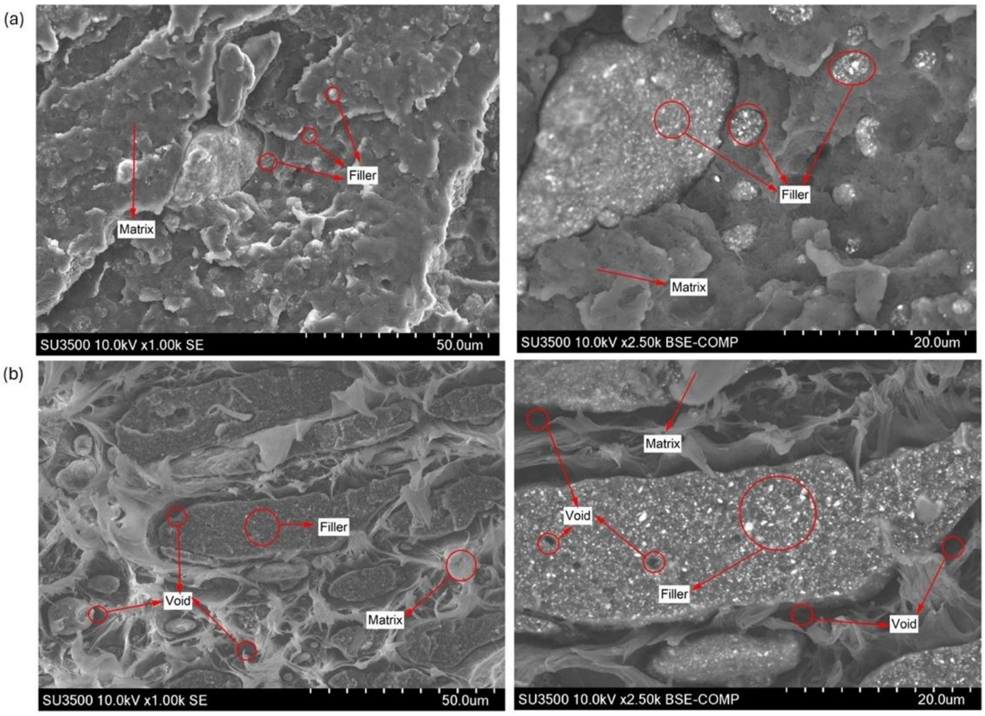

Figure 1. SEM images of high-density polyethylene (HDPE) matrix composite with (a) 30% epoxy filler with magnification 1000× (left) and magnification 2500× (right); (b) 40% epoxy filler with magnification 1000× (left) and magnification 2500× (right)

Effect of the Coupling Agent Composition

Figure 2 provides the results from the SEM analysis of the samples with 0% and 10% polypropylene grafted maleic anhydrate (PP-g-MA) composition. Based on Figure 2, the distribution of white particles as filler and the presence of voids indicate that the mixing process was imperfect. The higher the composition of the PP-g-MA coupling agent in the composite, the easier it is to see the distribution of the filler. Specimen with 0% PP-g-MA composition showed very little visible filler compared to PP-g-MA addition. This is due to the coupling agent forming a good bond between the matrix and filler. Meanwhile, as PP-g-MA was added, the filler began to bind to the matrix and was seen distribute in the composite. However, there is an optimum number of coupling agent additions to the composites. It is seen from the many voids or cavities formed when PP-g-MA with a composition of 10% is added. Following the results of mechanical tests that were also carried out, the optimum composition of PP-g-MA in the composite with waste polyester powder is 5%.

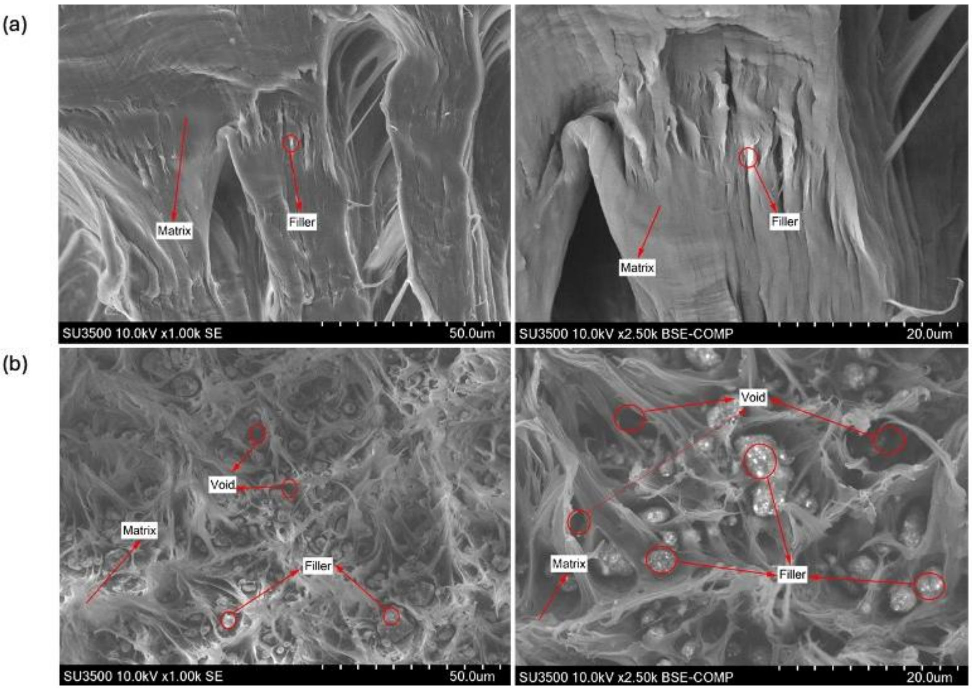

Figure 2. SEM images of HDPE matrix composite with epoxy filler coupled with (a) 0% PP-g-MA with magnification 1000× (left) and magnification 2500× (right); (b) 10% PP-g-MA with magnification 1000× (left) and magnification 2500× (right)

Fourier-Transform Infrared (FTIR) Analysis

Effect of Filler Composition

The FTIR spectra of the pure HDPE, HDPE with filler 20, 30, and 40% are presented in Figure 3. Sample with 0% HDPE (PE0) shows the existence of C-H bonding in wavenumber around 750 cm^{-1}, 1500 cm^{-1}, 2900 cm^{-1}, and C-C bonding in wavenumber around 1250 cm^{-1}. The addition of filler resulted in the presence of new functional group vibration of C-O bonding in wavenumber 1100 cm^{-1} and C=O bonding in wavenumber 1750 cm^{-1}. These bonding vibrations were not found in the pure HDPE without filler (PE0 samples). These vibrations are detected due to the bonding of HDPE and polyester filler with the coupling agent PP-g-MA, where maleic anhydride bonds with polyester, and PP in PP-g-MA bonds with HDPE. The increased polyester filler added to the HDPE matrix resulted in a peak change in the samples. The bonding between maleic anhydride and polyester resulted in the bonding of new esters and O-H bonding. The FTIR spectra of PE0, P1, P2, and P3 presented that the higher polyester filler added resulted in broader C=O and C-O peaks in the composites. The absorption peak around 1100 cm^{-1} and 1750 cm^{-1} in P1, P2, and P3 was broader compared to PE0 samples. This was due to the presence of ester groups between the matrix and filler. However, there is no slight difference in O-H transmission percentage in P1, P2, and P3 samples in wavenumber 3500 cm^{-1}.

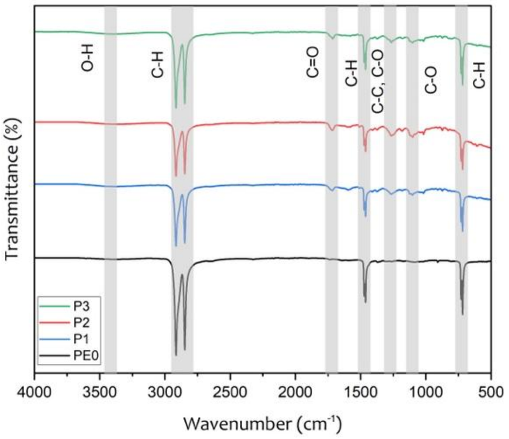

Figure 3. FTIR Spectra of HDPE matrix composite with epoxy filler composition 0 (PE0), 20 (P1), 30 (P2), and 40% (P3)

PP-g-MA functionated as a coupling agent where the polar maleic anhydride bonds with the filler –OH in polyester, while PP-g will bond with HDPE. PP-g-MA will form ester bonds based on the polarity of the material. The effect of filler composition in the composite can be indicated by the increasing number of ester bonds formed in the FTIR spectrum in wavenumber around 1700 cm^{-1}. The lower the transmittance of the bands, the higher the amount of C=O bonds. Figure 4 is the FTIR analysis in wavenumber 1800–1650 cm^{-1}, focusing on the C=O bond area, which has high polarity and is a part of the ester bond. This spectrum area is related to the interaction between the matrix and the filler.

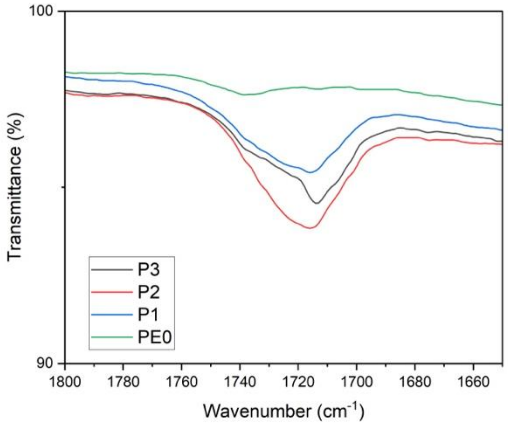

Figure 4. FTIR Spectra of HDPE matrix composite with the variation of epoxy filler composition in wavenumber 1800–1650 cm^{-1}

In the FTIR spectroscopy, the infrared wavelength was passed through the sample, and transmitted energy was recorded by the detector. If the sample contained certain functional groups, the energy will be reduced due to the existence of the certain functional group. The more functional groups detected in the sample, the lower the transmission percentage of the energy recorded by the FTIR spectroscopy. Figure 4 shows that the P2 sample with 30% polyester filler composition has the lowest transmission percentage in wavenumber around 1720 cm^{-1}. This indicates that the P2 sample has more C=O bondings in the sample. The increasing filler composition up to 40% resulted in an increasing the transmission percentage, which indicates a decrease in the number of C=O bonds. Based on the transmission percentage of C=O bonds in the sample, the optimum composition of added filler for compatibility in the composite is 30%.

Effect of PP-g-MA Composition

The FTIR spectra of the specimen with PP-g-MA variations 0, 2, 5, and 10% are presented in Figure 5. P4 sample with 0% PP-g-MA presented the peak of C-H bonding in wavenumber around 750 cm^{-1}, 1500 cm^{-1}, 2900 cm^{-1}, and C-C bonding in wavenumber around 1250 cm^{-1}. The addition of PP-g-MA resulted in the existence of C-O bonding in wavenumber 1100 cm^{-1} and C=O bonding in wavenumber 1750 cm^{-1}. PP-g-MA addition in the composite resulted in the formation of several bonds that cannot be found in the sample of pure HDPE. The influence of the PP-g-MA composition as a coupling agent on the compatibility and the interaction between the matrix and filler can be seen by the ester bonds (C=O) formed in the FTIR spectrum. The transmission percentage of C=O bonding at wavenumber 1800–1650 cm^{-1} is increased by the addition of PP-g-MA, as shown in Figure 6.

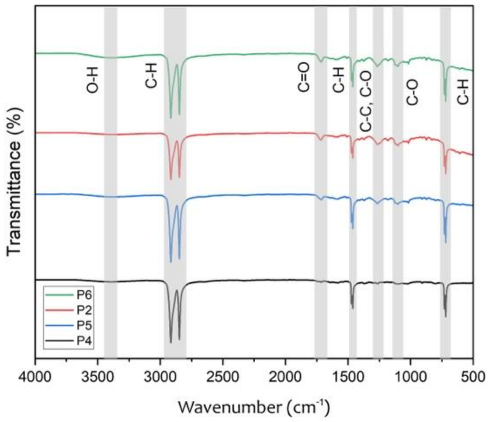

Figure 5. FTIR Spectra of HDPE matrix composite with polyester filler related to the variation of PP-g-MA composition 0 (P4), 2 (P5), 5 (P2), and 10% (P6)

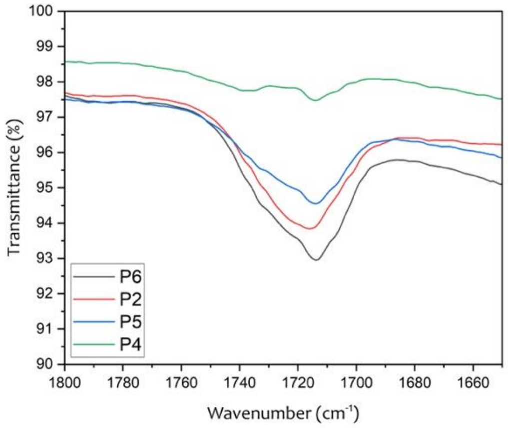

Figure 6. FTIR Spectra of HDPE matrix composite with polyester filler related to the variation of PP-g-MA composition in wavenumber 1800-1650 cm^{-1}

Figure 6 presents the FTIR spectra of the P2, P4, P5, and P6 samples in wavenumber 1800-1650 cm^{-1}**.** The increase in PP-g-MA composition decreased the transmission percentage of the sample. This indicates that the number of C=O bonds increases in the HDPE matrix composite with polyester waste powder filler. Based on the FTIR spectrum, the optimum level of PP-g-MA composition as a coupling agent is 10%.

Simultaneous Thermal Analysis (STA) Analysis

Effect of Filler Composition

The results from the thermogravimetric analysis (TGA) analysis of the samples are given in Figure 7. There is an influence of filler composition on the amount of composite mass loss that occurred up to 500°C of heating. The changes in the mass of the samples are caused by the oxidation and decomposition reactions in the specimens. The other reason was the physical processes such as desorption, evaporation, and sublimation [11]. PE0 sample or pure HDPE has a degradation temperature of 476.2°C. The temperature changes as the infiller composition increases. The degradation temperature (Td) of P1, P2, and P3 are increased with the highest value at 30% filler composition, which has a degradation temperature of 480.4°C. The addition of fillers to the HDPE matrix can improve the thermal stability of HDPE. Interaction between HDPE, polyester filler, and PP-g-MA resulted in the formation of the ester and hydroxyl group. This interaction can improve the temperature resistance of the composite. In addition, the interaction between the filler and the HDPE resulted in a role of lower matrix chain mobility between the matrix and fillers [12].

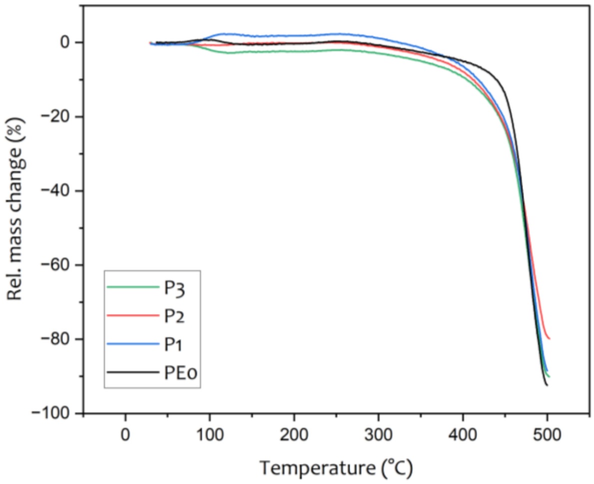

Figure 7. TGA curves of HDPE matrix composite with polyester filler composition 0 (PE0), 20 (P1), 30 (P2), and 40% (P3)

Differential scanning calorimetry (DSC) testing is also carried out to determine the melting temperature through endothermic reactions that occur in the composite when heated. The results of this test can be seen in Figure 8. It shows the endothermic reaction curve that provides the information of transition glass (T_g), curing temperature (T_c), and melting temperature (T_m). The sample of pure HDPE (PE0) was not provided T_g until the addition of 30% polyester powder waste. The peak of Tg of polyester appeared at 66.5°C. Based on the DSC curve, the filler composition influences the melting temperature of the composite. The melting temperature of the pure HDPE (PE0) is 133.8°C. With the addition of waste polyester powder fillers, the melting temperature value decreases to around 131°C. The trend is confirmed by previous work [13]. The curing temperature increases up to 30% filler addition with a value of 116.3°C and then decreases to 114.3°C with the addition of PP-g-MA by 10%. Increasing the filler composition causes the interaction between the matrix and the filler to decrease. Hence, the temperature required to melt the composite decreases [14]. The summary of T_g, T_c, T_m, and T_d is provided in Table 3.

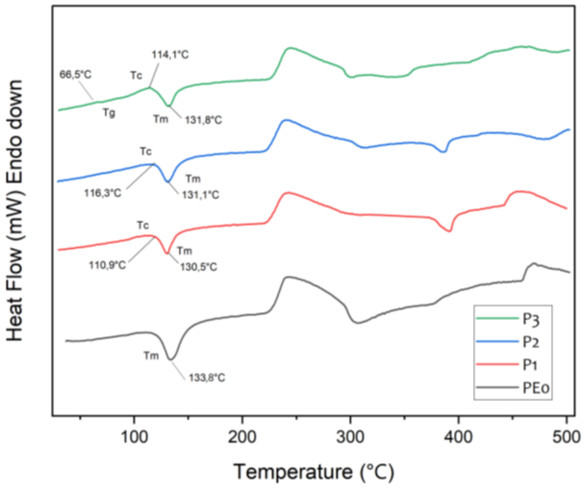

Figure 8. DSC curves of HDPE matrix composite with polyester filler composition 0 (PE0), 20 (P1), 30 (P2), and 40% (P3)

Table 3. Thermal analysis data TGA and DSC on the variation of filler composition

Sample	Filler Composition (%)	T_g (°C)	T_c (°C)	T_m (°C)	T_d (°C)

PE0	0	-	-	133.8	476.2
P1	20	-	110.9	130.5	479.1
P2	30	-	116.3	131.1	480.4
P3	40	66.5	114.1	131.8	477.4

Effect of PP-g-MA composition

The results from the TGA analysis of the samples are presented in Figure 9. Based on Figure 9, the composition of the PP-g-MA coupling agent influences the amount of sample mass loss during the heating up to 500°C. The highest degradation temperature was 480.4°C with a 5% PP-g-MA composition. Increasing the composition of PP-g-MA does not continue to increase the thermal stability of the composite. PP-g-MA, used as a coupling agent, works at the filler and matrix interface to form a composite interphase. As a result, when exposed to higher temperatures, unreacted chains in the polymer matrix will lead to composite degradation due to its lower thermal stability. In addition, a greater number of maleic anhydride groups can produce a higher amount of oxygen, accelerating the degradation process and reducing its thermal stability [15]. It is caused by the presence of impurities in the composite that can affect its thermal stability, decreasing it.

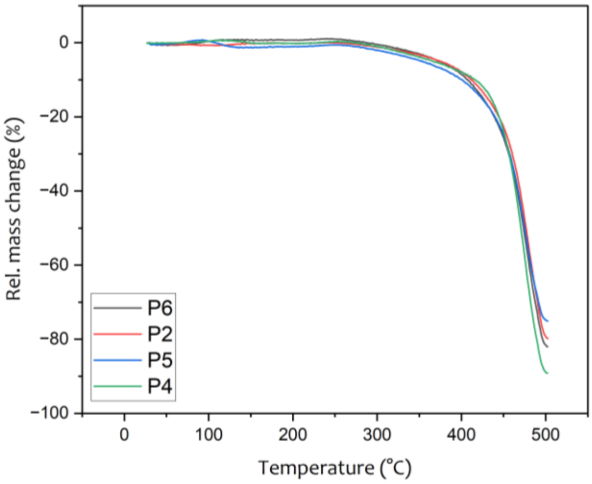

Figure 9. TGA curves of HDPE matrix composite with polyester filler variated by PP-g-MA composition 0 (P4), 2 (P5), 5 (P2), and 10% (P6)

The effect of PP-g-MA composition on the melting temperature of the composite can be observed through DSC testing. Based on Figure 10, the composition of PP-g-MA affects the melting temperature (T_m) of the composite. Increasing the composition of PP-g-MA tends to reduce the melting temperature of the composite. Table 4 shows the change of, T_c, T_m, and T_d of the composite by the increasing of PP-g-MA addition. The P4 sample has a melting temperature of 131.5°C and increases with the addition of PP-g-MA up to 5% by composition. The value then decreased to 129.7°C in the P6 sample with 10% PP-g-MA composition. PP-g-MA has a lower molecular weight when compared to the HDPE matrix. The low molecular weight of the bond between the matrix and the coupling agent increases the mobility of the polymer chains, resulting in a decrease in the temperature required to melt the composite [14].

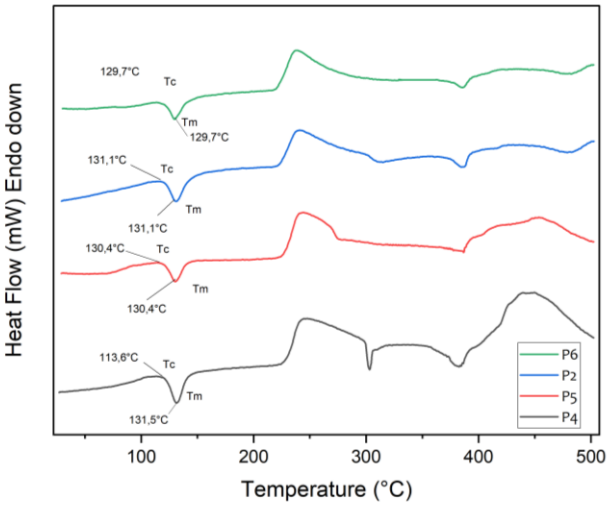

Figure 10. DSC curves of HDPE matrix composite with polyester filler variated by PP-g-MA composition 0 (P4), 2 (P5), 5 (P2), and 10% (P6)

Table 4. Thermal analysis data TGA and DSC on the variation of PP-g-MA composition

Sample	PP-g-MA Composition (%)	T_g (°C)	T_c (°C)	T_m (°C)	T_d (°C)
P4	0	-	113.6	131.5	474.4
P5	2	-	114.2	130.4	476.2
P2	5	-	116.3	131.1	480.4
P6	10	-	113.7	129.7	478.6

Tensile Strength

Effect of Filler Composition

From Figure 11, it can be seen that the tensile values of the composite reach the optimum values at a composition of 20%. The tensile strength values increase with increasing filler composition. The addition of filler to the composite aims to improve the mechanical properties of the matrix. In general, the more filler added, the more the mechanical properties of the composite will increase up to the optimum limit [16]. The tensile strength of pure HDPE is 7.52 MPa and produces a greater value until the addition of filler with a composition of 40%. However, the increase in tensile strength value increased only up to a filler composition of 20%, then decreased with increasing filler in the matrix. With polyester waste powder filler, an optimum tensile strength value of 8.70 MP was obtained.

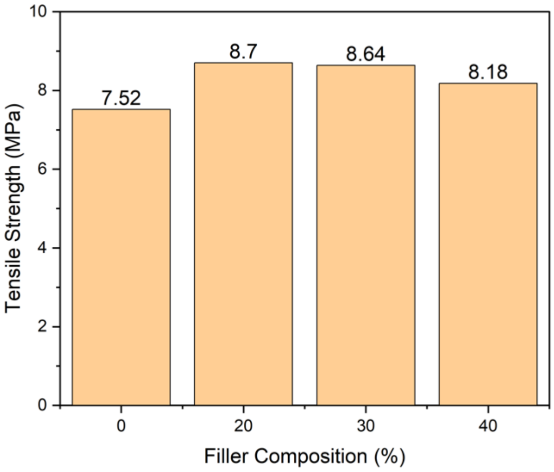

Figure 11. Bar graph of tensile strength of HDPE matrix composite with polyester filler composition 0 (PE0), 20 (P1), 30 (P2), and 40% (P3)

Effect of PP-g-MA Composition

Figure 12 shows the effect of PP-g-MA composition in HDPE and polyester filler. There is an increase in the tensile strength value of the sample with the addition of 5% PP-g-MA, then a decrease at 10% composition. This shows that PP-g-MA works as a coupling agent that improves adhesion in the interface area, resulting in polyester fillers that can increase the tensile strength value of the composite. Overall, the addition of PP-g-MA increases the tensile strength value of the composite. The optimum value of tensile strength is achieved when adding 5% PP-g-MA. The addition of 10% PP-g-MA exceeds the optimum limit for the use of a coupling agent, resulting in a decrease in the tensile strength value.

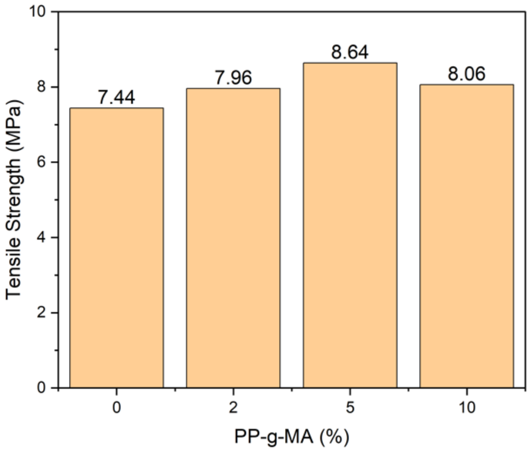

Figure 12. Bar graph of tensile strength of HDPE matrix composite with polyester filler variated by PP-g-MA composition 0 (P4), 2 (P5), 5 (P2), and 10% (P6)

Stiffness

Effect of Filler Composition

Stiffness refers to the degree to which an object resists deformation when subjected to an applied force. In contrast, flexibility is the opposite; the more flexible an object is, the less stiff it is. The results from the stiffness of the samples are given in Figure 13. In Figure 13, the stiffness value of the HDPE matrix increases when filler is added. Pure HDPE has a stiffness value of 0.03254 MPa, and a greater stiffness value is produced until the addition of filler with a composition of 40%. However, the increase in stiffness value only reached 20% composition, then decreased as the filler composition increased. This pattern was observed in previous work by Karolina et al. (2017) on the effect of natural fiber fillers on the mechanical properties of polyethylene composite. The ability of the fillers to integrate into the polymer structure is the key to determining the mechanical properties of the composite. The optimization of the size, amount, shape, and distribution of the filler can enhance the composite properties [17]. The composite with waste polyester powder filler has an optimum stiffness value of 44.10 kN/m.

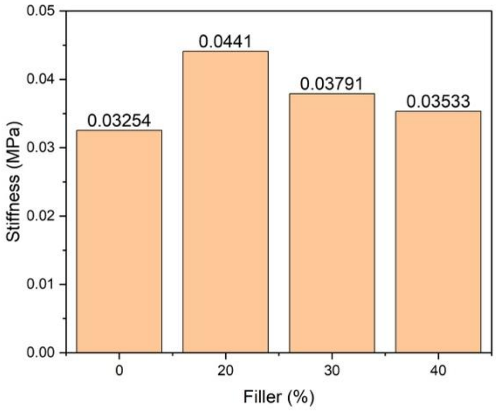

Figure 13. Bar graph of stiffness of HDPE matrix composite with polyester filler composition 0 (PE0), 20 (P1), 30 (P2), and 40% (P3)

Effect of PP-g-MA Composition

Based on Figure 14, the addition of PP-g-MA increases the stiffness value of the composite. As tensile strength value, the composite stiffness value increased until the addition of a 5% PP-g-MA coupling agent, then decreased when the PP-g-MA composition was 10%. Composites without PP-g-MA experienced a decrease in stiffness values when compared to pure HDPE. The poor bonding between the filler and matrix will reduce the stiffness value, so the addition of a coupling agent is required. With the presence of PP-g-MA as a combining agent, the stiffness value can be increased. With the addition of 5% PP-g-MA, an optimum value of 42.37 kN/m was achieved for the composite with polyester filler. The stiffness value decreased with the addition of 10% PP-g-MA, indicating that this composition had exceeded the optimum limit for using a coupling agent in the composite. This phenomenon is confirmed by Yang et al. (2023), that there is a limited number of coupling agents that are able to increase the mechanical properties. When the coupling agent composition is added too much, the excessive amount of coupling agent will affect the interfacial bonding force between filler and matrix. This will result in a decrease in its mechanical properties, including stiffness [18].

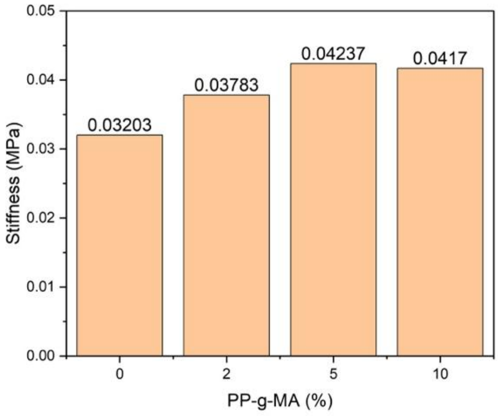

Figure 14. Bar graph of stiffness of HDPE matrix composite with polyester filler variated by PP-g-MA composition 0 (P4), 2 (P5), 5 (P2), and 10% (P6)

CONCLUSION

The results presented that polyester waste powder can be utilized as a filler in high-density polyethylene (HDPE) matrix composites with the addition of polypropylene grafted maleic anhydrate (PP-g-MA) as a coupling agent. The addition of polyester filler increases the mechanical properties, thermal properties, and morphology of HDPE matrix composites with optimum conditions. The morphology of the composite shows that as the filler composition of the polyester waste powder is added, the homogeneity of the filler in the matrix increases. The addition of the PP-g-MA composition also plays a role in reducing visible pores in the composite. The optimum filler composition to obtain the best mechanical properties with waste polyester powder filler is 20%. Meanwhile, the optimum filler composition to obtain the best thermal properties with waste polyester powder filler is 30%. The optimum PP-g-MA composition as a coupling agent to obtain the best mechanical and thermal properties is 5%, with an HDPE matrix composition of 70% and polyester powder coating waste composition of 30%.

ACKNOWLEDGEMENT

The author would like to thank the lecturer of the Green Polymer Technology Laboratory, Department of Metallurgical and Materials Engineering of Universitas Indonesia, for ideas, endless support, and feedback. The authors would like to thank the Polymer Laboratory, Department of Metallurgical Engineering and Materials, Faculty of Engineering, Universitas Indonesia, for providing facilities and laboratory testing; Research Center Physics, Indonesian Institute of Sciences, Puspiptek Area, Serpong, South Tangerang for STA analysis; As well as the Chemical Laboratory, Indonesian Institute of Technology (ITI), for providing the facilities for the hot melt mixing process.

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