Wood plastic composites from chopped and pelleted waste plastic bags: effect of concentrations and reprocessing on flexural modulus and strength

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Abstract. The utilization of waste plastic bag, especially as a matrix for wood plastic composites, is expected to reduce the environmental problems throughout the world caused by its use. Wood plastic composites were manufactured via melt mixing of chopped or pelleted waste plastic bags, sawdust and polyethylene grafting maleic anhydride (MAPE) according to Extreme Lattice Mixture - Design of Experiment (DoE). The effects of concentrations and reprocessing of waste plastic bags on flexural modulus of elasticity and strength of composites were analyzed. In general, flexural modulus of composites from chopped and pelleted waste are increased but still below the value of SNI 8154–2015. Moreover, the flexural strength of the resulted composites from chopped waste also increased than that of the pelleted one. Some of the formulas of composites from chopped waste met the value required by SNI 8154–2015. On the contrary, the flexural strengths of composites from pelleted waste are decreased than that of the virgin one. This is probably due to the existence of interaction between pelleted waste and sawdust that prevented the waste plastic to perfectly melted, hence acted as stress concentration sites. Furthermore, the resulted composites were optimized for flexural modulus using response optimizer plot in order to achieve modulus 2000 MPa that required by the standard. However, the optimized flexural modulus of composites from chopped and pelleted waste was in the range of 1500 MPa, which is far below the standard. Therefore, reprocessing of chopped waste into pellets is not necessary due to inferior properties of composites from pelleted waste than that of the chopped one.

Keywords: wood plastic composites, waste plastic, chopped, DoE, twin screw

1. Introduction

Wood plastic composites (WPC) have been studied since more than a decade ago. The technology has been applied in many products as construction materials as well as automotive. It can be produced from recycled materials as polyethylene (PE). However, most of recycled PE used for wood plastic composites was from rigid polymer as milk bottle.
According to Parker [1], people around the world use billions of tons of plastic products for the last ten years. 20% of the plastic products were plastic bags made from PE [1]. As reported by Halweil [2], around 160,000 plastic bags are produced every second globally. In Indonesia, 11 million plastic bags are produced annually, giving Indonesia as the second largest producer of plastic bag after China. However, the huge number of plastic bag production leaves problems to environment and waste management. At present, only 14% of waste plastic bags are incinerated while another 5% are recycled [3]. Nevertheless, these are also huge amounts of potential recycled PE to be utilized.

Most of these waste plastic bags are recycled into another plastic bags, which has short lifetime. In order to increase the lifetime of waste plastic bags, those wastes can be used as matrix for wood plastic composites. Many groups study the utilization of recycled plastics from different sources such as bottle, water can, etc., as the matrix in wood plastic composites [4–8]. However, there are limited reports on the study of waste plastic bags as the matrix of wood plastic composites. Morris and Cooper [9] processed waste plastic bags into wood plastic composites using compression molding machine and studied the decaying thereof [9]. While El-Haggar et al. [10] manufactured wood plastic composites using waste plastic bags as the matrix by adding wood fiber and talc as the filler [10]. Therefore, further studies is needed to the advancement of utilizing of waste plastic bags in wood plastic composites.

In this research, we study the effect of concentration and reprocessing of wood plastic composite manufactured from waste plastic bags and sawdust on flexural strength and modulus elasticity of wood plastic composites in accordance with SNI 8154 – 2015.

### 2. Materials and methods

#### 2.1. Materials

Random waste plastic bags from laystall were washed by water and chopped into small pieces. Some of the chopped were extruded to form dense and compact pellets. Chopped and pellet waste plastic bags were used as matrices in wood plastic composites. Admix of hardwoods sawdust (< 80 mesh) was used as filler. High density polyethylene (HDPE) Titanvene 6070EA (MFR 7.5 g/10 min, flexural modulus 1700 MPa) purchased from Lotte Chemical Titan Nusantara, maleic anhydride and benzoyl peroxide both purchased from Merck, were used to prepare polyethylene-graft-maleic anhydride (MAPE) according to the route optimized by Ujianito and Radini [11]. The resulted MAPE was used as compatibilizer for manufacturing wood plastic composites.

#### 2.2. Manufacturing WPCs

Formulas for compounding wood plastic composites (WPC) were generated in Minitab 16, based on Extreme Lattice Mixture - Design of Experiment (DoE). In order to obtain the high flexural properties of composites, the maximum concentrations of chopped or pellet waste plastics bags; sawdust and compatibilizer were set at 80%, 55% and 10%, respectively [12–15]. Table 1 shows all formulas for this experiment.

The composites were compounded using twin-screw extruder Collins ZK 25 according to conditions shown in table 2. Sawdust was dried at 80 °C in an oven for 24 hours prior to be processed.

### Table 1. Formula of composites using chopped and pelleted waste plastic bags

| Run | waste plastic (wt.%) | sawdust (wt.%) | MAPE (wt.%) |
|-----|----------------------|---------------|-------------|
| 1   | 60.0                 | 35.0          | 5.0         |
| 2   | 70.0                 | 22.5          | 7.5         |
| 3   | 52.5                 | 45.0          | 2.5         |
| 4   | 45.0                 | 55.0          | 0.0         |
| 5   | 35.0                 | 55.0          | 10.0        |
| 6   | 70.0                 | 27.5          | 2.5         |
| 7   | 80.0                 | 20.0          | 0.0         |
| 8   | 80.0                 | 10.0          | 10.0        |
| 9   | 47.5                 | 45.0          | 7.5         |
Table 2. Process conditions for manufacturing wood plastic composites (WPC)

| Parameter | Temperature (°C) | Screw Speed (rpm) |
|-----------|-----------------|-------------------|
| T<sub>1</sub> T<sub>2</sub> T<sub>3</sub> T<sub>4</sub> T<sub>5</sub> T<sub>6</sub> T<sub>7</sub> | 40 170 175 180 185 190 190 | 60 |

Table 3. Process conditions for compression moulding

| Parameter               | Steps | 1     | 2     | 3     | 4     | 5     |
|-------------------------|-------|-------|-------|-------|-------|-------|
| Temperature (°C)        |       | 190   | 190   | 190   | 190   | 40    |
| Pressure (bar)          |       | 5     | 5     | 5     | 5     | 5     |
| Time (minute)           |       | 5     | 5     | 5     | 5     | 15    |

Table 4. MFR and ΔH<sub>m</sub> of chopped and pelleted waste plastic bags

| Parameter               | MFR (g/10 min) | ΔH<sub>m</sub> (J/g) | T<sub>m</sub> (°C) |
|-------------------------|----------------|----------------------|-------------------|
| waste plastic bag       |                |                      |                   |
| chopped                 | 1.638          | 60.225               | 125.90            |
| pelleted                | 2.722          | 70.374               | 128.50            |

To assure homogeneity, all materials were hand-mixed shortly before compounding. The resulted composites compound was air-cooled and granulized. The granules were moulded to form sheet using Collins P300P machine according to conditions listed in table 3. The resulted sheet was cut into 150 mm length and 50 mm width specimens. All specimens were pre-conditioned at temperature of 23 ± 2 °C and relative humidity of 50 ± 10 % for more than 24 hours in advance of further testing.

2.3. Measurements and testing

2.3.1. Measurement of melt flow rate, melting temperature and degree of crystallinity. Melt flow rates (MFR) of chopped and pelleted waste plastic bags were measured using CEAST MFI 7062 instrument following ASTM D1238-2013. The melt density of PE at 190 °C (0.761 g/cm<sup>3</sup>) was used to calculate MFR. Differential Scanning Calorimetry (DSC) Perkin Elmer was used to obtain heat of fusion (ΔH<sub>f</sub>) and melting temperature (T<sub>m</sub>) of chopped and pelleted waste plastic bags. Degree of crystallinity (X) was calculated using equation (1) from ΔH<sub>f</sub> and theoretical ΔH<sub>f</sub> of 100% crystalline HDPE (290 J/g).

\[ X = \frac{\Delta H_f}{\Delta H_{f0}} \times 100\% \]  

2.3.2. Measurement of flexural modulus and strength of WPCs. All composites were tested in accordance with ISO 16978 using Universal Testing Machine (UTM) Shimadzu AG-X Plus 50 kN to characterize their flexural modulus and strength. The crosshead speed was 0.3 MPa/sec. The flexural modulus was calculated in the load ranging from 10 % to 40 % of maximum load.

3. Results and discussion

3.1. Melting enthalpy and melt flow rate.

Table 4 shows MFR, ΔH<sub>m</sub> and T<sub>m</sub> of chopped and pelleted waste plastic bag. The MFR of the pelleted waste is higher than that of the chopped one, giving that the pelleted waste is easier to be processed due to its lower viscosity. It also means that average molecular weight of the pelleted waste is lower than that of the chopped one, attributed to chains scission during reprocessing of the former [16–17].

Table 4 shows that ΔH<sub>f</sub> of chopped and pelleted waste plastic bags are 60 J/g and 70 J/g, which corresponds to 23 % and 27 % degree of crystallinity, respectively. The pelleted waste has slightly higher crystal content compared with the chopped one. This is probably due to the lower molecular weight pelleted waste crystallize more facile [18]. During the reprocessing of the pelleted waste, long...
Table 5. Flexural modulus of elasticity and strength of wood plastic composites

| waste plastic | modulus (E) (MPa) | strength (σ) (MPa) |
|---------------|------------------|-------------------|
|               | chopped | pelleted | chopped | pelleted |
| control       | 554     | 587      | 16.7    | 19.4     |
| 1             | 961     | 1173     | 19.3    | 17.1     |
| 2             | 972     | 998      | 23.1    | 16.2     |
| 3             | 1505    | 1230     | 18.1    | 13.6     |
| 4             | 1528    | 1437     | 14.0    | 11.3     |
| 5             | 1462    | 1537     | 16.8    | 13.4     |
| 6             | 1034    | 1123     | 20.9    | 17.9     |
| 7             | 916     | 974      | 20.7    | 16.7     |
| 8             | 674     | 745      | 19.2    | 14.9     |
| 9             | 1491    | 1228     | 20.8    | 14.5     |
| Average       | 1171    | 1161     | 19.2    | 15.1     |

polymer chains were truncated by the screw’s shear resulted in shorter and less entangled molecules that promote easier crystallization [17]. This is in agreement with the melting temperature results. The pelleted waste melted in higher temperature compared with the chopped one due to the difference in crystal content [19].

3.2. Flexural modulus and strength of WPCs

Table 5 shows flexural modulus of elasticity and strengths of chopped and pelleted waste plastic bags as well as the composites. Flexural properties of the pelleted waste are lower than that of the chopped one due to the differences in degree of crystallinity of both samples. It is well known that for HDPE, the higher the degree of crystallinity, the higher the modulus and strength [9].

Furthermore, it can be seen in table 5 that the average flexural modulus of the composites from chopped and pelleted waste plastic bags are lower than that of the chopped one due to the differences in degree of crystallinity of both samples. It is well known that for HDPE, the higher the degree of crystallinity, the higher the modulus and strength [9].

On the other hand, flexural strength of four composites from the chopped waste satisfies the SNI 8154–2015 criterion (20 MPa). The highest flexural strength (23 MPa) is obtained from formula 2 (chopped waste 70.0 %, sawdust 22.5 %, MAPE 7.5 %). On the contrary, no flexural strength of the composites from pelleted waste complies with the standard. This is probably due the interaction between pelleted waste and sawdust during composites processing. Sawdust of hardwood is three times more thermal insulative in comparison with HDPE (thermal conductivity of sawdust is 0.16 W/m °C vs 0.51 W/m °C of HDPE). In the presence of more thermal insulative sawdust, pelleted waste experienced obstruction to melt in the barrel and required higher processing temperature. This resulted in some poorly melted polymers and phase separation between matrix and filler, which acted as stress concentration sites. Moreover, denser and more compact pelleted waste entered the barrel more rapidly than sawdust which resulted in less homogeneous compound. On the other hand, chopped waste melted easier due to its lower T. Further more, chopped waste produced more shear that generated extra heat during the processing due to its higher melt viscosity that enhanced the liquefying of the polymer [20].

3.3. Model generation and optimization.

All results were analyzed in Minitab 16 to generate models that describes the characteristics of the composites. Equation (2) to equation (5) are the resulted models for each composite type and properties. As stated previously, no flexural modulus of the composites meet the specification that required by the standard. Therefore, all data were optimized using response optimizer plot in Minitab 16 for flexural modulus of elasticity. The results are depicted in figure 1. Figure 1 shows that in the
range of formulas used in this study. Neither composites from chopped nor pelleted waste can reach the requirement (2000 MPa). Maximum values obtained from the models are in the range of 1500 MPa, which predicted to be achieved with the same formula for both chopped and pelleted waste, i.e. 35% chopped or pelleted waste, 55% sawdust, and 10% MAPE.

4. Conclusions
Wood plastic composites from chopped and pelleted waste plastic bags were successfully manufactured using twin-screw extruder. Flexural modulus and strength of the resulted composites were measured. No flexural modulus of the composites satisfied the requirement value of SNI 8154–2015 standard due to the low intrinsic property of waste plastic bags. The flexural moduluses of composites from chopped and pelleted waste were about similar. However some of the composites from chopped waste managed to comply with the flexural strength value that required by the standard, probably due to good liquefying of polymer and blending with fillers. Therefore, based on the data resulted from this study, further processing of chopped waste plastic bag into pellet is not required for the manufacturing of wood plastic composites.

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