The effects of particle size and content on Morphology and Mechanical Properties of Rice Straw and Coal Fly Ash filled-Polypropylene Composites

Ninik Lintang Edi Wahyuni, *Bambang Soeswanto

Chemical Engineering Department, Politeknik Negeri Bandung

*bambang.soewanto@yahoo.com

Abstract. Polypropylene is a superior type of polymer due to its properties including flexibility, semi-transparent appearance, easily dyed, heat-retaining and hydrophobia. The percentage of recycled polypropylene is minimal which cause environmental pollution. To overcome the environmental problems caused by polypropylene waste, it can be utilized to produce efficient and economically-added product such as thermal insulation composites. The paper is focused on obtaining the technique and operating condition of injection molding to manufacture composite from polypropylene matrix, the influence of composition and particle size of fillers on composite mechanical properties.

1. Introduction

Polypropylene is a superior type of polymer due to its properties including flexibility, semi-transparent appearance, easily dyed, heat-retaining and hydrophobia. Therefore, it is widely used for various products. The percentage of recycled polypropylene is minimal which cause environmental pollution.

To overcome the environmental problems caused by polypropylene waste, it can be utilized to produce efficient and economically-added product such as thermal insulation composites. The ideal insulation material has such characteristics as capable to withstand medium heat and rigidity. To obtain the stiffness and thermal insulation properties of polypropylene, it is necessary to add filler material (Grozdanov et al., 2006). In order to obtain composites with superior properties, including strong, lightweight, non-abrasive, able to withstand heat, cheap and environmentally friendly (Garkhail et.al, 2000 and Sahu, 2014), Saranya (2014) studied the effect of filler levels (fly ash and fiber) on the insulation properties of polypropylene composites, without explanation of filler’s particle size. Zhang (2011) states that smaller particle size of Al2O3 filler increases thermal insulation properties of HDPE (high density polyethylene) composites. Srisawat et al. (2009) uses silica (SiO2) as filler on neat polypropylene, which produces composite with better thermal stability due to strong adhesion between polypropylene and silica. The function of silica as a filler can be replaced by coal fly ash which has high silica content (40% to 60%), relatively low density, spherical particle shape with smooth surface, small particle size, evenly distributed internal stress on the matrix, and its low cost (Sreekanth et al., 2009).
The paper is focused on obtaining the technique and operating condition of injection molding to manufacture composite from polypropylene matrix, the influence of composition and particle size of fillers on composite mechanical properties.

2. Experimental

2.1. Materials

Neat Polypropylene Resin type HI10HO with specific gravity of 0.9 and melt flow rate of 10 g/10 min was obtained from PT Candra Asri Petrochemical, rice straw was obtained from rice field in Cimahi, West Java, coal bottom ash was obtained from textile industry in Cimahi, West Java. Xylene (technical grade) was obtained from a chemical store in Bandung (Bratachem), Indonesia.

2.2. Methods

Rice straw from the rice field was soaked in water for two days. Afterwards, it was dried with oven at 105°C and was ground to a certain size. The composites were manufactured with various of filler and matrix composition, i.e. fly ash content (10-20%), fine straw content (10-20%). The rice straw, coal fly ash, polypropylene at a certain proportion and xylene (5 times weight of PP ) were placed into a mixer and heated to the melting temperature of polypropylene (173°C), then the hot agglomerate were transferred to the shallow cast (2 mm deep) where hot agglomerate were cooled down to room temperature in the fume hood, and let the rest of xylene to evaporate.

The dried sheet of agglomerate was cut to 1-2 mm. The agglomerate flake was fed into the feed container of the injection molding apparatus, was heated to 170-190 °C for 15 minutes, and molded with a pressure of 5 bars to form specimens of a certain shape and dimension according to the testing standard. Cooling of the specimen was done at room temperature, then the specimen was removed from the mold. Density measurement and tensile tests using ASTM E-8 standard were carried out for characterization of composites.

3. Result and Discussion

The injection molding is a combination of heating and pressing methods. The heating of the feed uses a belt heater where heat is passed through a jacket encasing the feed tube (conductive heat transfered through the tube wall). Compression of feed was carried out using hydraulic cylinder moved by air compressor, with maximum pressure of 6 bars.

3.1. Composite Mechanical Properties

3.1.1. Effect of Filler Composition on Tensile Strength of Composite

To study the effect of filler composition on composite tensile strength, the experiment was carried out by varying fillers composition (PP 60-100%, Straw 10% 20%, CFA 10-30%). The result of composite tensile test is presented in Figure 1.
The addition of filler to the composite results in a decrease in tensile strength (tensile strength of neat PP: 35 MPa). In the sample with proportion of PP: CFA: RS = 6: 1: 3 there was a minimum decrease of tensile strength (36%). This is likely due to the weak bonding between the matrix and filler, thereby decreasing the composite tensile strength. The condition in which the decrease in tensile strength is minimal occurred at the composite with the largest portion of straw (30% w). This is in accordance with work of Min et al. (2016), on polypropylene wastes composite with filler of 60 mesh wheat straw (10-50% w). Flexural strength of WS/PP composite increased with WS content from 20 to 50wt.% but decreased at 65wt.%. This is because the higher the content of WS fiber led to agglomeration problem. The agglomeration of WS fiber is an indication of poor bonding or low interfacial adhesion strength between the filler and PP matrix.

While Iwamoto et al. (2014) study on polypropylene composites with ligno cellulose nano fiber filler (LCNF) of diameters less than 20 μm obtained a tensile strength drop of up to 10% at 10% w portion of LCNF.

The decrease in tensile strength was explained in the research of Fu et al. (2008), about composite of PP-CaCO3 with particle diameter of 0.08 μm (10% v), 1.3 μm (45% v) and 58 μm (30% v) where the tensile strength drop from 33 MPa (neat PP) to 29 MPa, 23 MPa and 12 MPa respectively. For the 0.01 μm particle composites the trend is reversed, which tensile strength enhanced by 10% on 10% v. filler loading. This phenomenon can be explained because small diameter particles have large surface area. On a large contact surface area the tensile strength is also great because of the efficient power transfer mechanism.

In a study conducted by Nath et al. (2009) on the composite of PP-CFA (without mentioning particle size), it was found that in the CFA fraction of 20%, 45% and 60% there was a continuous decline of tensile strength. Tensile strength tests performed at 50 °C and 70 °C showed an increase in composite tensile strength at a 20% of CFA loading. This can be explained because at elevated temperatures the thermoplastic polymer enhanced free volume, which being filled up by the CFA, and causing a better wetting between PP and CFA.

While Zhang et al.(2011) made a composite of high density poly ethylene (HDPE) with filler of Al2O3 with particle size of 0.1 μm to 10 μm, found that the size of the filler particles on the micrometer order gave a less strong bond, and reduction of the tensile strength was proportional to the increase in particle size at the same volume fraction, i.e. 0.8%, 41.5%, and 53.7% for particles with a diameter of 0.5 μm, 4.7 μm and 10 μm for 30% of Al2O3 volume. The tensile strength of composites increases with the decrease of the alumina particle size. When the Al2O3 of 0.01 μm loading is 30 % vol, the tensile strength enhanced by 12 % higher than the neat HDPE.

### 3.1.2. Effect of Filler’s Particle Diameter on the Density of Composite
To study the effect of particle size on composite density, two composites of different CFA particle size were manufactured (Dp 45 μm and 0.75 mm).

There was a difference in the density of the same CFA loading but different particle size, due to the difference in the density of different particle sizes of CFA (2.03 g/cm³ and 3.36 g/cm³ for Dp 0.75 mm and 45 μm respectively). On both sizes of CFA particles the measured composite density is less than the calculated density.

Figure 2. Effect of Particle Diameter and CFA Loading on Composite Density

This phenomenon indicates that the adhesion between CFA and PP is less strong, resulting in a cavity between the filler and the matrix and enlarge the composite volume.

In the study of Onuegbu et al. (2011) on polypropylene composites with filler of snail shell powder, it was found that the composite density decreases by the increase of the particle size of snail shell powder for a certain filler loading. This is due to the fine particle size of filler distributed more evenly within the matrix.

3.1.3. Effect of Molding Temperature on Composite Density

To study the effect of molding temperature on composite density, the molding temperature was varied for CFA: PP = 30% : 70%, with molding pressure of 5 bar, and the result was presented in Figure 3.

Figure 3. Effect of Molding Temperature on Composite Density

Figure 3 shows that an increase in molding temperature from 175°C to 195°C provided a higher composite density up to 9.07%. This indicates that the higher the heating temperatures enhanced melting process and decreased the viscosity of PP, resulting in a denser composite.

4. Conclusion
The resulted composite was a homogeneous product, obtained by polypropylene (PP) grafting method with xylene, optimum injection molding achieved at temperature of 195°C and pressure of 5 bars. Composites with CFA and rice straw fillers with particle size of 54 μm and 0,10 mm respectively, obtained the best composition at PP: CFA: RS (w) = 6: 1: 3, with the smallest tensile strength drop of 36%, tensile strength of 2.24 kg / mm² and thermal conductivity (calculation) of 0.1493 W / m.K.

Acknowledgements

The authors gratefully acknowledge financial support by the Ministry of Research, Technology and Higher Education, Directorate of Research and Community Service, Directorate General of Research and Development Reinforcement, in accordance with the Contract of Research of Fiscal Year 2017, Number 025 / SP2H / LT / DRPM / IV / 2017, April 3, 2017

References

[1] Bledzki A. K., Mamun, A. A., Lucka-Gabor, M., Gutowski, V. S. 2008, The effects of acetylation on properties of flax fibre and its polypropylene composites, eXPRESS Polymer Letters Vol.2, No.6 (2008) 413–422 Grozdanov, A., Buzarosvka, G., Bogoèva-Gaceva, M., Avella, M., Errico, M.E.,

[2] Gentille, G. (2006). Rice straw as an alternative reinforcement in polypropylene composites. HAL Id: hal-00886354, https://hal.archives-ouvertes.fr/hal-00886354.

[3] Garkhail, S .K., Heijenrath, R.W., Peijs, T., 2000, Composites Based On Natural Fibres And Thermoplastic Matrices. Queen Mary College, University Of London.

[4] Min Yu, Runzhou Huang, Chunxia He, Qinglin Wu, and Xueni Zhao, 2016, Hybrid Composites from Wheat Straw, Inorganic Filler, and Recycled Polypropylene: Morphology and Mechanical and Thermal Expansion Performance, International Journal of Polymer Science, Volume 2016, Article ID 2520670, 12 pages, http://dx.doi.org/10.1155/2016/2520670, Hindawi Publishing Corporation.

[5] Nath, D.C.B., Bandyopadhyay, S., Yu, A., Blackburn, D., White, C., 2009, Correlation of Mechanical and Structural Properties of Fly Ash Filled-Isotactic Polypropylene Composites, World of Coal Ash (WOCA) Conference – May 4-9, 2009 in Lexington, KY, USA, http://www.flyash.info.

[6] Onuegbu G. C., Igwe, I.O., 2011, The Effects of Filler Contents and Particle Sizes on the Mechanical and End-Use Properties of Snail Shell Powder Filled Polypropylene, Materials Sciences and Application, 2, 811-817, doi: 10.4236/msa. 2011.27110 Published Online July 2011 (http://www.SciRP.org/journal/msa) Copyright © 2011 SciRes.

[7] Ramme; Tharanjyil, 2013, We EnergiesCoal Combustion Product Utilization Handbook, 3rd edition, Wisconsin.

[8] Sahu, Y.K. (2014). Study on the Effective Thermal Conductivity of Fiber Reinforced Epoxy Composites. Department of Mechanical Engineering National Institute of Technology, Rourkela, Odisha (India)

[9] Saranya, E., Satyanarayana, G., Prasad, A.S., (2014). Experimental Investigation of Thermal Properties of Borassus Flabellifer Reinforced Composites and Effect of Addition of Fly Ash-International Journal of Engineering Trends and Technology (IJETT) – Volume 15 No 8 – Sep 2014. ISSN: 2231-5381 http://www.ijettjournal.org Page 379

[10] Shao, Y.F., Xi-Q.F., Bernd, L., c, Yiu, W. M., Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate– polymer composites, 2007, Composites: Part B 39 (2008) 933–961, www.sciencedirect.com.

[11] Sreekanth, M.S., Bambole, V.A., Mhaske, S.T., Mahanwar, P.A., (2009). Effect of Particle Size and Concentration of Flyash on Properties of PolyesterThermoplastic Elastomer Composites.
Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.3, pp 237-248, 2009. jmmce.org Printed in the USA. All rights reserved

[12] Verma, D. et al (2012) Bagasse Fiber Composites - A Review. J. Mater. Environ. Sci. 3 (6) (2012) 1079-1092 Verma et al. ISSN : 2028-2508 CODEN: JMESC 1079

[13] Yunida Sofiana (2010) Pemanfaatan Limbah Plastik Sebagai Alternatif Bahan Pelapis (Upholstery) Pada Produk Interior, INASEA, Vol. 11 No.2, Oktober 2010: 96-102

[14] Zhang et al. (2011). The effects of particle size and content on the thermal conductivity and mechanical properties of Al2O3/high density polyethylene (HDPE) composites. eXPRESS Polymer Letters Vol.5, No.7 (2011) 581–590