Influence of Screw Speed on the Mechanical Properties of Twin-Screw Extruded Rice Husk Flour Recycled Thermoplastic Composites

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***Abstract*—** High loading rice husk flour (RHF) biocomposites based on recycled high density polyethylene (rHDPE) / recycled polyethylene terephthalate (rPET) blend matrices were fabricated through a two-step extrusion and hot pressing. Ethylene-glycidyl methacrylate (E-GMA) compatibilizer was used to enhance the compatibility of the immiscible rHDPE/rPET blend. A coupling agent, maleic anhydride polyethylene (MAPE) was used to increase the fibre-matrix interfacial adhesion. In this study, the effect of screw rotation speed (30, 40, 50 and 60 rpm) on mechanical properties of composites was examined. The tensile and flexural showed the decreasing trend as increasing screw speed. Interestingly, elongation at break and impact strength results presented the reverse (increasing) trend.

***Keywords*—** Recycled polymer blend, agro waste, biocomposite, extrusion.

I. Introduction

THE worldwide annual collection of post-consumer and post-industrial plastic wastes is roughly a few million tonnes per year. There is still remarkable number of plastics end up in landfill although the recycling capacity for plastic wastes is increasing [1]. In Peninsular Malaysia, the total amount of municipal solid waste generated in 2010 has increased from 7 million tonnes annually to 7.7 million tonnes and plastic wastes account for 24% of them [2]. Most of them are polyethylene (PE) and polyethylene terepthalate (PET), which are extensively used in packaging industry [3]. As a result, both HDPE and PET bottles have promising recycling prospect since they attract a lot interest in finding new possibilities for the use of post-consumer plastics as new products due to the large amount generated daily and the lower cost compared to virgin plastic [1], [3]. Due to the incompatibility of HDPE and PET, the incorporation of compatibilizer which concentrates at the interface, aids to enhance the interfacial adhesion as well as refine and stabilize the blend morphology [1].

Rice husk (RH) is an agro-waste that own a land area of approximately 680 thousand hectares and around 840 thousand tons of RH is produced every year in Malaysia. RH is a cellulose-based fibrous material with a broad range of aspect ratios [3]. The introduction of RH into polymer matrices promotes useful characteristics, such as biodegradability, lightweight, toughness, and resistance to weathering, and also makes the final products more economically competitive [2]. At this point, agricultural materials are gradually becoming the interest of worldwide in the field of composite materials, which can be alternative for limited source of forest. These composites are currently be used in the building construction industry, such as frames for windows and doors, slidings, decks, interior panels, and in the automotive industry for interior parts like door panels and trims. In comparison to wood-based composites, the RH-filled composite obtains higher resistance to termite and biological attack, and also superior dimensional stability upon exposure to moisture [3]. Maleic anhydride polyethylene (MAPE), a common coupling agent utilized to enhance the interfacial adhesion between PE matrix and lignocellulosic fibres. The anhydride group of MAPE covalently bonds with the hydroxyl groups available on the surface of the natural fibres, whereas the ethylene block of MAPE facilitate the wetting of the polymer chains [2].

Effective mixing is essential for achieving optimal distribution of RH and maximizes the properties of the composites, which is depending upon the compounding and processing conditions [4]. the compounding conditions vary with several factors such as species of the thermoplastics and natural fiber, moisture content of the natural fiber, weight ratio of the polymeric matrix and natural fiber, mixing machine type, and compounding steps [5]. In the case of extrusion compounding, certain extrusion parameters such as screw speed and temperature must be considered to optimize the effect of extrusion on composite properties. In this present

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work, the objective was to investigate the effect of screw rotation speed on mechanical properties rice husk flour (RHF)/recycled polymer blend biocomposites.

II. Experimental

A. Raw Materials

The polymer matrices used was recycled high-density polyethylene (rHDPE, density of 923 kg/m^3 and melt flow index of 0.72 g/10min at 190°C) and the recycled polyethylene terephthalate (rPET, T_g of 74.1 °C, cold crystallization peak temperature of 119.9 °C and melting peak temperature of 252.5 °C), were obtained from a local plastic recycling plant. An ethylene-glycidyl methacrylate (E-GMA) copolymer (trade name Lotader AX8840) with a melt index of 5 g/10 min (190°C, 2.16 kg) and a glycidyl methacrylate content of 8%, was used as compatibilizing agent for immiscible blends. Rice husk flour (RHF, 100-mesh size) and maleic anhydride polyethylene (MAPE) were utilized as agro-waste filler and coupling agent for RHF reinforced biocomposites, respectively. RHF was dried in an oven at 100°C for 24 h before use. All the raw materials were obtained from factory namely BioComposites Extrusion Sdn. Bhd.

B. Preparation of the composites

RHF reinforced rHDPE/rPET blends were produced in a three-stage process. Prior to compounding, the formulated raw materials were first tumble-mixed. In the first extrusion, the recycled polymer blend (rPB) pellets based on rHDPE and rPET were made by using the a laboratory scale co-rotating twin screw extruder (Thermo Prism TSE 16 PC). The four barrel temperatures from the feeding to die zones were set as 250, 270, 240 and 190 °C. The screw rotating speed was 30 rpm. The weight ratio of rHDPE/rPET/E-GMA was fixed at 75/25/5 (wt/wt/wt). The extrudates were then cooled and granulated into pellets by a crusher.

In second extrusion, the rPB pellets were melt-blended with dried rice husk flour using the same twin screw extruder as above, with a temperature profile of 195, 215, 210 and 190°C at various (30, 40, 50, 60) rpm. The rice husk flour to plastic weight ratios used was 70/30 (wt/wt). The loading level of MAPE was fixed at 3% based on the total weight of composites. The extrudates were then cooled and granulated into pellets.

In the third stage, hot/cold press process (LP50, LABTECH Engineering Company LTD) was used to produce the specimen panels for testing. The fine sample pellets were compression molded at 200°C under 1000 psi. In the hot press process, the times of preheating, venting and full pressing were set at 3, 2 and 5 min, respectively, whereas cold press was set at 5 min to cool the specimen sheets.

C. Characterization

Both tensile and flexural testing were conducted according to ASTM standard D 638-03 (type I) and D 790-03, respectively, using a universal testing machine (model Testometric M350-10CT) at speed of 5 mm/min. The Izod impact testing was carried out following ASTM standard D 256-05 at velocity of 3.46 ms-1, load weight of 0.452 kg and calibration energy of 2.765 J, using Ray-Ran Universal Pendulum Impact System. All the reported results of mechanical tests are the average of five replicates for each formulation.

III. Results And Discussion

Generally, the screw rotation speed is associated to the shear stress applied and residence time of composite melt during compounding in extruder [6]. The increase of screw speed up will cause two distinct phenomenons: (1) produce higher shear stress on the melt and thus promotes better distribution of filler within the polymer matrix which resulting in improved mechanical properties, (2) reduce the residence time of melt in the extruder which causing incomplete melt compounding process. Zhang et al. reported that the technical role of reaction to fabricate composites needs high shear stress at polymer melt state and suitable residence time [4].

Fig. 1 depicts the tensile strength and modulus of the RHF biocomposites as a function of screw speed. The maximum tensile strength (21.7 MPa) and modulus (735.4 MPa) values were recorded at 30 rpm. The results showed that the tensile strength and modulus decreased gradually with increasing the screw speed from 30 to 60 rpm. Biocomposites made at 60 rpm exhibited the lowest tensile strength and modulus, which decreased by 15% and 27% compared to those extruded at 30 rpm. This was attributed to the sufficient shear rate obtained at 30 rpm, as further increasing screw speed will decrease the residence time of reaction in the extruder which had short barrel length with an L/D ratio of 25. Besides, due to the RHF is heat sensitive, the extruder screw speed was restricted by the maximum shear rate that the composites can experience without degradation. On the other hand, when the polymer was extruded at higher rates over a certain level, air entrapment and excessive melt temperatures may occur in the extrudate [7].

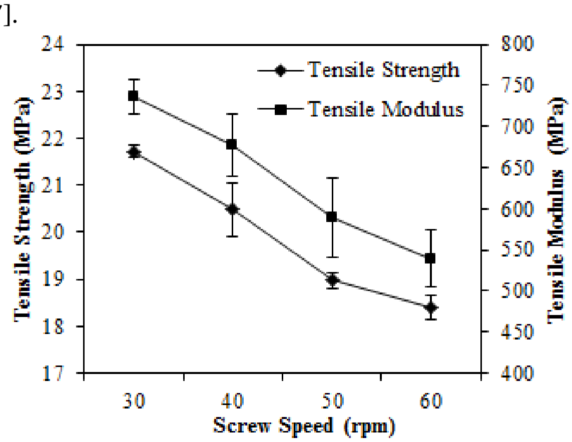

Fig.1 Tensile strength and modulus of the biocomposites as a function of screw speed

Fig.2 demonstrates the effect of different screw speed on the flexural strength and modulus of RHF reinforced composites. The flexural properties results showed same (downward) trend as tensile properties in Fig. 1, for all samples processed with increasing rate of extrusion. As can be observed, the highest values of flexural strength (45.7 MPa) and modulus (4178.2

MPa) were obtained for composites produced at 30 rpm. It was noticed that the decrease of flexural properties was slightly greater than that in tensile properties, which was up to 47% and 38%, for flexural strength and modulus respectively. This reduction might be due to some weakness points like lacked adhesion of RHF fibre with the host matrix and incomplete melting of RHF/polymer blend mixture during extrusion. Since, as mentioned above, the barrel length of extruder in this study was at L/D ratio of 25, which was considered short, thus the residence time of melt was insufficient for the reaction to occur if screw speed higher than 30 rpm, in the range of investigated.

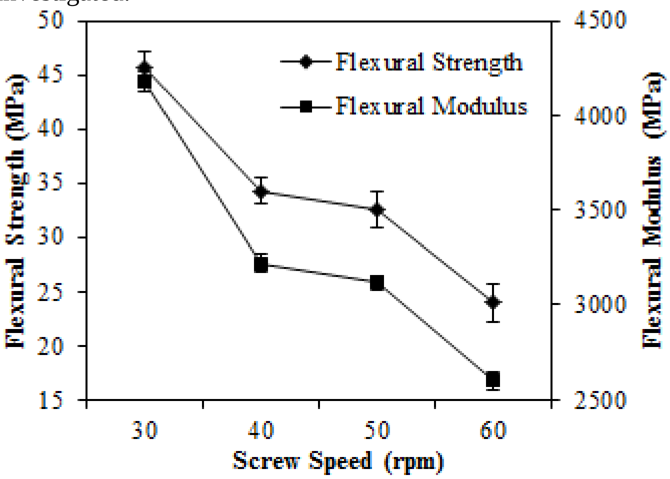

Fig.2 Flexural strength and modulus of the biocomposites as a function of screw speed

The elongation at break and impact strength of biocomposites extruded at different screw speed is shown in

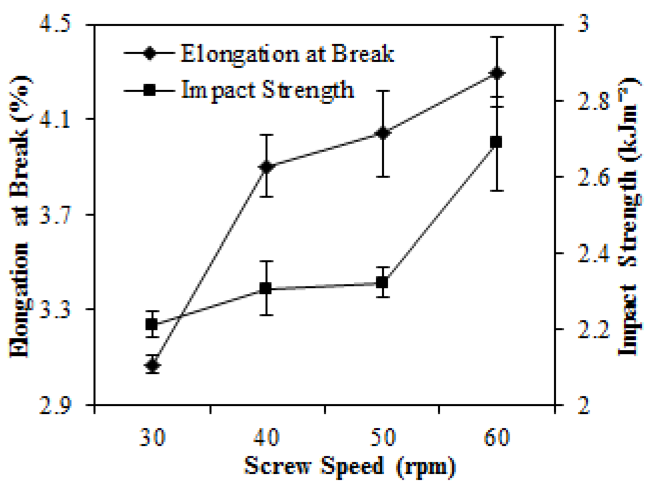

Fig. 3 Elongation at break and impact strength of the biocomposites as a function of screw speed

Fig. 3. The increasing of screw speed had positively influenced both the elongation at break and impact strength of the composites. As screw speed increased from 30 to 60 rpm, the elongation at break and impact strength of composites increased by 39% and 23%, from 3.1% and 2.2 kJm^{-2} respectively. The increasing trend of elongation at break and impact strength was matched with in decreasing trend of rHDPE/rPET/RHF composites. This could be ascribed to the better break up of viscous RHF particles during the extrusion in the melt compound which was apparently increased the fracture toughness and ductility of RHF reinforced composites [6].

IV. Conclusion

RHF reinforced recycled polymer blend biocomposites have been prepared by melt-blending method. General, with the increasing screw speed, the tensile and flexural properties of the biocomposites were gradually decreased; whereas, the elongation at break and impact strength were increased. With the technical importance of this work, the industry field may gain useful manufacturing information and knowledge in order to produce products in large output volume and minimal energy consumption with the maximal performance properties.

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References

[1] R. S. Chen, M. H. Ab Ghani, M. N. Salleh, S. Ahmad, and S. Gan, “Influence of blend composition and compatibilizer on mechanical and morphological properties of recycled HDPE/PET blends,” Mater Sci Appl., vol. 5, No. 13, pp. 943-952, Nov. 2014.

[2] R. S. Chen, M. H. Ab Ghani, S. Ahmad, M. N. Salleh, and M. A. Tarawneh, “Rice husk flour biocomposites based on recycled high-density polyethylene/polyethylene terephthalate blend: Effect of high filler loading on physical, mechanical and thermal properties,” J Compos Mater., pp. 1-13, May 2014.

[3] R. S. Chen, M. H. Ab Ghani, M. N. Salleh, S. Ahmad, and M. A. Tarawneh, “Mechanical, water absorption, and morphology of recycled polymer blend rice husk flour biocomposites,” J Appl Polym Sci., vol. 132, no. 8, pp. 1-12, Sep. 2014.

[4] Z. X. Zhang, C. Gao, Z. X. Xin and J. K. Kim, “Effects of extruder parameters and silica on physico-mechanical and foaming properties of PP/wood-fiber composites, ” Compos Part B Eng., vol. 43, no. 4, pp. 2047-2057, June 2012. http://dx.doi.org/10.1016/j.compositesb.2012.01.047

[5] J. Z. Lu, Q. Wu and Negulescu II, “Wood-fiber/high-density-polyethylene composites: Compounding process,” J Appl Polym Sci., vol. 93, no. 6, pp. 2570-2578, Sep. 2004. http://dx.doi.org/10.1002/app.20707

[6] B. Kord, I. Ghasemi, A. Najafi and A. Kiaeifar, “Effect of screw speed on mechanical and morphological properties of PP/sawdust flour/montmorillonite hybrid nanocomposite,” World Appl Sci J., vol. 13, no. 5, pp. 1147-1151, 2011.

[7] B. A. C. Siatong, L. G. Tabil, S. A. Panigrahi and W. J. Crerar, “Effect of Extrusion Parameters on the Physical Characteristics of Extruded Flax Fiber-Reinforced Polyethylene Composites,” CSAE/SCGR. Winnipeg, Manitoba 2005