Influence of wood species on properties of injection mould natural flour-HDPE composites

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Abstract. Four combinations of wood flour, HDPE, and maleic anhydride (MA) include; (1) rubberwood:HDPE (30:70), (2) rubberwood: HDPE:MA (30:67:3), (3) palm oil:HDPE (30:70), and (4) palm oil:HDPE:MA (30:67:3) were studied. The injection moulding machine was used to produce wood plastic composites (WPCs). Maleic anhydride is an ingredient in bonding agents used to manufacture wood plastic composites. Extrusion molding process was conducted to prefabricate WPCs. Consequently, the effect of temperature and pressure ranging from 180, 190, 200°C and 2300, 2400, 2500 bar on injection molding was evaluated. Mechanical properties were tested including flexural testing and tensile testing according to ASTM D790 and D638, respectively. Hardness testing according to ASTM D2240 and scanning electron microscope (SEM) were also performed. Five replications were done on each test. The result showed that rubberwood:HDPE (30:70) gave a highest strength. The values of ultimate tensile strength, flexural strength, and hardness are 24.9 MPa, 33.3 MPa and 67.2 shore D, respectively. Finally, the uniform distribution of particle in WPCs, examined through SEM was achieved.

1. Introduction

Wood plastic composites (WPCs) have made a name for themselves in extruded decking and fencing boards. WPCs are competitive with calcium carbonate-filled or talc-filled PP in cost, performance, and processing. As they contain up to 50% organic fibers, WPCs offer a material option that is more environmentally friendly than typical petrochemically derived polymers. WPCs have the advantage of lower density resulting to reduce cost and can be beneficial in transportation and other uses on light weight applications. These include automotive, construction, sports, toys, and other consumer goods. WPCs can be made with a variety of plastics, such as polyethylene [1], polypropylene [2], polystyrene [3], and high-density polyethylene (HDPE) [4]. HDPE has a higher strength-to-density ratio and therefore was selected to study. Many natural fibers such as rice hulls, palm fiber waste, or rubberwood flour can utilize to make biocomposites. Many studies noted that maleic anhydride has proven to be having a bridging effect between wood filler and the polymer matrix, resulting in improvement of material mechanical properties when used as compatibilizer [5]. This element is able to improve the WPC flow characteristic. The selection of wood species and coupling agent is very important to suit to the WPC product application and processing methods requirement.

In the process of fabrication, hot press [6], extrusion [7, 8] and injection moulding [9] are among the most popular techniques. However, good candidates for injection molding with WPCs are parts with thick walls and ones that would benefit from excellent rigidity and dimensional stability. However, some
injection molders are hesitant to experiment with new materials like wood plastic composites because of inconsistent quality, inconsistent supply, and generally greater difficulty in working with WPCs in comparison with more familiar injection molding materials. However, recent developments in the manufacture of WPC compounds have significantly improved the quality, consistency, and capability of this environmentally friendly material. Good candidates for injection molding with WPCs are parts with thick walls and ones that would benefit from excellent rigidity and dimensional stability. While WPCs are best suited to parts with thick walls, processors can compensate for thinner walls by blending WPC with additional neat polymer. WPCs offer the combined properties of wood and plastic—excellent moisture barrier plus the ability to be screwed or nailed like wood, along with an organic look and feel. In addition, WPCs reduce a molder’s exposure to increasing petroleum prices, reduce the energy costs associated with production, and produce an end-product with great structural rigidity, an aesthetically pleasing finish, and new, highly marketable performance capabilities.

This study was focused on two parts: (1) evaluating the effect of wood species which are rubberwood flour (RWF) and palm oil flour (POF) and (2) evaluating the effect of maleic anhydride on the properties of WPCs. Therefore, the objective of this research is to evaluate the effect of wood species and coupling agents on the properties of WPC.

2. Experimental

2.1. Materials
Recycled high density polyethylene, supplied by Withaya Intertrade Co., Ltd. in Samutprakarn, Thailand in the pellet form was used in this study. Maleic anhydride obtained from Sigma-Aldrich Pte Ltd, Singapore, was used as coupling agent. Rubberwood flour from S.T.A Furniture Group Co., Ltd. and palm oil flour from local industry in Songkhla, Thailand were used as lignocellulosic filler. The RWF and POF were sieved through 80 meshes and dried in an oven at 110°C for 8 h. The dried wood flour was stored in a sealed plastic container to prevent the absorption of water vapor. WPCs with 30% of wood flour and 70% of HDPE or 67% and 3% of MAPP were prepared. Each formulation in table 1 was weighed and stirred for 5 min to obtain uniform dispersion.

| Table 1. Formulations used in making wood plastic composites. |
|------------------|-----------------|-----------------|-----------------|-----------------|
| Sample ID        | Mixture formulation (%) | Rubberwood | Palm oil | HDPE | MA |
| r30h70           | 30               | -             | 70        | -   |
| r30h67m3         | 30               | -             | 67        | 3   |
| p30h70           | -                | 30            | 70        | -   |
| p30h67m3         | -                | 30            | 67        | 3   |

* r30h67m3 = rubberwood flour(30):HDPE(67):maleic anhydride(3)
  p30h67m3 = palm oil wood flour(30):HDPE(67):maleic anhydride(3)

2.2. WPCs Processing
The sample preparation was carried out in two stages. In the first stage, RWF and POF along with HDPE were premixed and extruded using the twin-screw extruder model SHJ-36 from En Mach Co., Ltd. In the second stage, The WPC samples were then injection moulded by 50-ton press moulding machine model Arburg Allrounder 320C. The temperature of the mould was ranged from 180 to 200°C with the pressure in the range of 2,300 to 2,500 bar. Test procedures of tensile testing, flexural testing, and hardness testing were conducted according to the ASTM-D 638, 790, and 2240, respectively. High magnification micrographs on the microcellular structure of WPC produced were examined with scanning electron microscope (SEM) model FEI Quanta 400 (Czech Republic) working at 15 kV.
2.3. WPCs testing

Three tests of WPCs were carried out. Firstly, the WPCs specimens of dimensions 19 mm x 165 mm x 3.2 mm were subjected to tensile test as per ASTM-D-638-98, using the Instron Universal Testing Machine (Model 5582). A crosshead speed of 5 mm/min and a gauge length of 50 mm was used for carrying out the test. Secondly, the composite specimens of dimensions 25 mm x 80 mm x 3.2 mm were taken for flexural test, under three point bending, using the same Instron Universal Testing Machine (Model 5582), in accordance with ASTM-D 790-92, at a crosshead speed of 1.3 mm/min and a span length of 50 mm. Lastly, the same specimens of dimensions 25 mm x 80 mm x 3.2 mm as for flexural test were evaluated for hardness test, using the Teclock Durometer (Model GS-702N), in accordance with ASTM-D 2240. Each of the above tests was evaluated at room temperature (25°C) for five replications. The mean values and corresponding standard deviations along with the measurement uncertainty values for the experimental data were reported.

3. Results and Discussions

3.1. Mechanical properties

The effect of wood species and different amounts of maleic anhydride on the mechanical properties of wood-HDPE composites was shown in figures 1 and 2. It was observed in figure 1 that the tensile and flexural strengths of the rubberwood-HDPE composites are higher than that of the palm oil wood-HDPE composites. The reason is rubberwood generally has higher tensile stress perpendicular-to-grain (28 kg/cm²) than that of palm oil wood (10.53 kg/cm²) [10] and therefore improve the strengths of the composites. In addition, the SEM micrographs of wood flour/HDPE composites in figure 3(a) and (b) showed that the rubberwood flour had less porosity than that of palm oil wood resulting in increasing the strength of the composites. On the other side, the porosity of palm oil wood could be easily filled with polymer as shown in figure 3(b) resulting in poor stress transfer in the composite materials. When adding the maleic anhydride as coupling agent, the tensile and flexural strength of the composites were decreased i.e. from 24.9 to 20.6 MPa for rubberwood composites-tensile strength. Furthermore, the composites with maleic anhydride made from rubberwood flour or palm oil wood has approximately the same values of the tensile and flexural strength i.e. 20.6 and 20.5 MPa for rubberwood and palm oil wood composites-tensile strength. As can be seen in figure 3(c) and (d), the SEM micrograph of the composites made from both rubberwood and palm oil wood could not clearly indentify the difference. This is in good agreement with the mechanical testing result.

The tensile and flexural modulus of the composites as shown in figure 2 decreased with addition of the maleic anhydride. Furthermore, the palm oil wood-HDPE composites appeared to give higher tensile and flexural modulus than that of the rubberwood-HDPE composites. It indicates that the composites made from palm oil wood can be stretched when a load is applied rather than rubberwood.
Figure 1. The strength of wood flour/HDPE composites versus differential wood species and amounts of maleic anhydride

Figure 2. The modulus of wood flour/HDPE composites versus differential wood species and amounts of maleic anhydride
3.2. Hardness properties

The hardness of wood flour/HDPE composites was found in the range of 65.4 to 67.2 shore D as shown in figure 4. The hardness of all composites are not significantly different. This is because all composites were pass through the same injection mould process providing the similar surface property. However, the highest hardness value (67.2 shore D) was obtained from the rubberwood composites without maleic anhydride.
Figure 4. The hardness of wood flour/HDPE composites versus differential wood species and amounts of maleic anhydride

4. Conclusions
The mechanical properties of composites were affected by the species of the wood flour and the maleic anhydride used as a coupling agent. It was found that wood flour/HDPE composites made from rubberwood provided the better mechanical properties that that of palm oil wood. Morphological evidence was in good agreement with the mechanical results. Howerever, there is unaffected on the hardness from both wood species and addition of maleic anhydride.

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