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ORIGINAL PAPER

Water resistance and thermal stability of hybrid lignocellulosic filler–PVC composites

Hojatollah Kiani · Alireza Ashori · S. Ahmad Mozaffari

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Abstract In this study, composites based on polyvinyl chloride (PVC), pulp fiber (PF), and wood flour (WF) were made by injection molding. The effects of two variable factors, namely the filler form and filler loading level, on the composite physical properties were examined. The result clearly showed that the major part of water absorption was due to water absorption of PF. It was found that the water absorption in the lignocellulosic material base composites is significantly higher than the neat PVC. Besides, the water absorption increased sharply with increasing cellulosic filler loadings in the composites. In case of hybrid composites, the rate of water uptake correlated with percentage weight of WF, lower WF (higher PF) loadings in composites exhibit higher rate of absorption. The higher onset of degradation temperature indicates the improved thermal stability of the samples. In other words, the result clearly illustrates that the thermal property of the composites increases after using PF and further increases after addition of WF.

Keywords Lignocellulosic filler · Polyvinyl chloride (PVC) · Thermal stability · Water absorption

Introduction

Polyvinyl chloride (PVC) is one of the most commonly used plastics in our society, and its main applications include pipes, electric wires, window profiles, siding, etc. [1]. In 1993, Andersen Corporation (Bayport, MN) began producing wood fiber-

H. Kiani
Kian-Plast Sepahan Company, Sohrevardi (Simin) Ave., Esfahan, Iran

A. Ashori (✉) · S. A. Mozaffari
Iranian Research Organization for Science & Technology (IROST),
P.O. Box 15815-3538, Tehran, Iran
e-mail: ashori@irost.org

reinforced PVC subsills for French doors. These components typically contain 40% wood in PVC extruded to net shape [2]. Further development led to a wood–PVC composite window line. Recently, wood fiber reinforced PVC is getting more popular because of its acceptable mechanical properties, moisture, and fungus resistance, long lifetime, wood-like surface performance, and recyclability [3]. Some weakness of this material including high water absorption and low thermal stability imposes restriction on its application, which signals need for additional research on this important product. PVC resin shows relatively high water absorption compared with polyolefin. With the existence of hydrophilic lignocellulosic fillers, PVC/natural fiber composites tends to have higher water absorption rate than pure PVC, which further affects mechanical properties and structural stability of the composites [1].

The objectives of this study were: (a) to investigate the influence of fiber type and loading level on water resistance and thermal stability of the composites and (b) to evaluate the effects of the different mixing formulations of cellulosic materials on the above-mentioned physical properties. It is to be noted that the mechanical properties of this study were published elsewhere [4].

Materials and methods

Materials

Two different forms of poplar (*Populus deltoides*) were used as reinforcing filler: pulp fiber (PF), and wood flour (WF). The fibers were produced by chemi-mechanical pulping process. The fresh sawdust from local mill was ground into flour form using a Thomas-Wiley mill to pass through a 45-mesh screen (354 μm), and then was dried to less than 3% moisture content.

PVC, a product (Poliran PV S-6058) of Bandar Imam Petrochemical Company, Iran, was used as polymer matrix. The PVC polymer was in the form of powder with a bulk density of 550–610 g/L and a viscosity of 85–92 cm^3/g.

Preparation of composites

Various blending formulations and their mass ratios are listed in Table 1. It is to be noted that all the blends for hybrid composites were made with cellulosic materials (WF + PF) to PVC mass ratio of 40/60 (w/w); this value amount was selected because it is typical of many industrial formulations and represents optimum balance between performances and cost. In the first stage, the raw materials were physically premixed based on the formulations before being fed into the first zone of the extruder. All the experiments were performed in a co-rotating twin-screw extruder (Collin). The melt temperature at the die was 185 °C and the rotation speed was 60 rpm. The extruded strand was passed through a water bath, granulated, and dried at 105 °C for 24 h to remove any moisture. The resulting granules were subsequently injection molded at 190 °C to produce standard ASTM specimens.

Table 1 Formulations of the used experimental composites

Codes	PF (wt%)	WF (wt%)	PVC (wt%)
A1	10	–	90
A2	20	–	80
A3	30	–	70
A4	40	–	60
A5	45	–	55
A6	50	–	50
A7	55	–	45
B1	–	10	90
B2	–	20	80
B3	–	30	70
B4	–	40	60
B5	–	45	55
B6	–	50	50
B7	–	55	45
AB1	35	5	60
AB2	30	10	60
AB3	25	15	60
AB4	20	20	60
AB5	15	25	60
AB6	10	30	60
AB7	5	35	60

Water immersion test

The water absorption test was carried out following ASTM D570. The samples were immersed in distilled water at 23 ± 1 °C for 80 days. Before testing, the weight of each samples were measured. Samples were removed at certain periods of time, wiped with tissue paper to remove the excess water on the surface and immediately weighed.

Thermogravimetric analysis

Thermogravimetric analysis (TGA) measurements were carried out using a thermo gravimetric analyzer on 8-mg samples, over a temperature range from 30 to 700 °C, at a heating rate of 10 °C/min. TGA was conducted in a high quality nitrogen atmosphere with a flow rate of 15 mL/min to avoid unwanted oxidation. Each sample type was measured in triplicate.

Results and discussion

Water absorption

One of the important properties to be evaluated for WPCs is water absorption, since it can limit their use. The high water absorption of the WPCs may be an indicative of difficulties during processing, such as incomplete curing of the thermoset matrix, or of the presence of voids or cracks or even poor matrix/fiber adhesion. Figure 1a and b shows the percentages of the water uptake for the composites at different periods of immersion, which vary depending upon the filler form and filler loading level. The water absorption of the pure PVC, however, was very low (1%) due to its hydrophobic nature. In general, polymers do slightly absorb moisture, indicating that moisture is absorbed by the cellulosic material in the composite. The water absorption of WPCs is due to the hydrogen bonding of the water molecules to the free hydroxyl groups present in the cellulosic cell wall materials and the diffusion of water molecules into the filler/matrix interface. Additionally, a large number of porous tubular structures present in fiber accelerate the penetration of water by the so-called capillary action. As can be seen from Fig. 1a and c, the water absorption increased sharply with increasing PF and cellulosic filler loadings in the composites. On the other hand, it is also clear that water uptake of all composites increased with increase of immersion time, reaching a certain value at saturation point where no more water was absorbed and the composites water content remained constant. According to Das et al. [5], initially, water saturates the cell wall (via porous tubular and lumens) of the fibers, and next water occupies void spaces. As shown, there is significant difference on the amount of water absorption when PF was used. In other words, the composites made with 55 wt% PF (A7) showed the highest percentage of water absorption compared to the other formulations.

On the other hand, the composites containing 10 and 20% lignocellulosic filler by weight exhibited less water absorption than those containing 50 and 55% of the filler, because of the increased number of microvoids caused by the larger amount of poor bonded area between the hydrophilic filler and the hydrophobic matrix polymer. Water is easily absorbed by these voids.

The effect on the water absorption of hybrid composites at different weight percentages of lignocellulosic materials in the composites are shown in Fig. 1c. In case of hybrid composites, because of constant lignocellulosic material (40 wt%) in all blends, the different water absorptions among all manufactured composites can be attributed to the role of PF and WF. The rate of water uptake correlated with percentage weight of WF, lower WF (higher PF) loadings in composites exhibit higher rate of absorption. The rate of water uptake increased in the order: neat PVC (lowest) < AB7 < AB6 < AB5 < AB4 < AB3 < AB2 < AB1 (highest). A lowest water uptake occurred at 5% WF in PVC composites. Weight gain upon exposure to water increased as the percentage of WP increased for all composites tested. This could be possible due to a large number of porous tubular structures present in fiber accelerate the penetration of water by the so-called capillary action.

Thermal stability

The thermal stability of lignocellulosic filled polymer matrix composites is a very important parameter for the processing and usage of these materials. The manufacture of such composites requires the mixing of fibers and matrix at high temperatures, so the degradation of the biomaterial can produce undesirable effects on the properties. In this work only one TGA graph of weight loss as a function

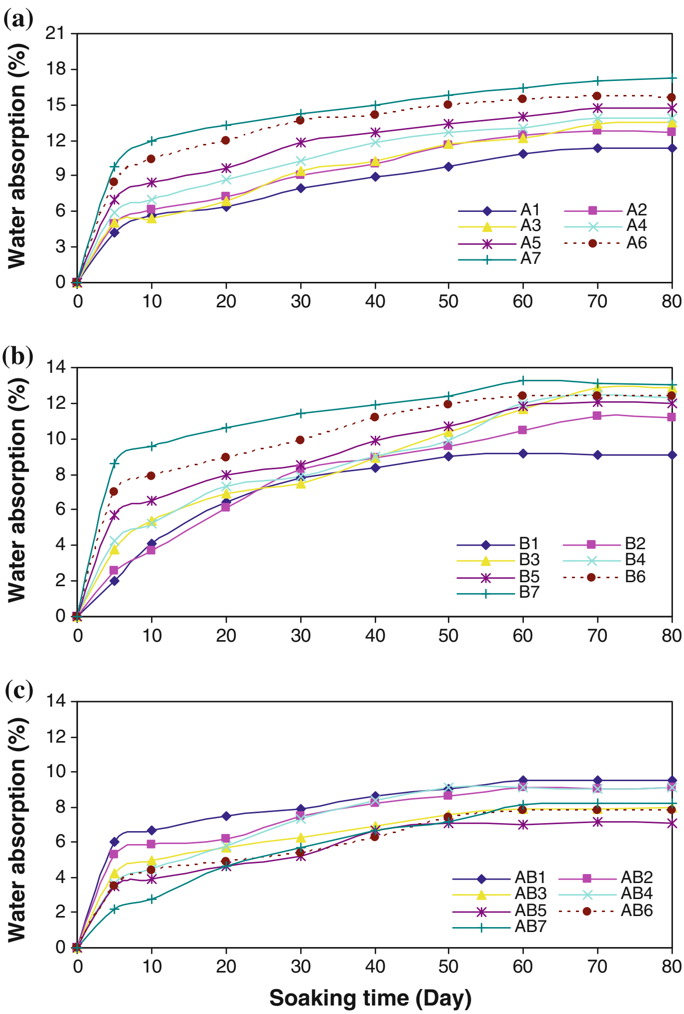

Fig. 1 Long-term water absorption of the composites

of temperature is presented (Fig. 2). This thermogram shows the typical thermal decomposition behavior for neat PVC and three typical combinations (A1, B1, and AB7). As shown, the initial degradation of neat PCV began at 300 °C with a weight loss of 86% while the initial degradation of other samples was varied in the range of 330–345 °C. The higher onset of degradation temperature indicates the improved thermal stability of the samples B1 and AB7. In other words, these results clearly illustrate that the thermal property of the composites increases after using PF and further increases after addition of WF. The most likely explanation is that the degradation of lignocellulosic fibers follows a two-stage process with the low-temperature stage from degradation of hemicellulose and the high-temperature stage from degradation of lignin [6].

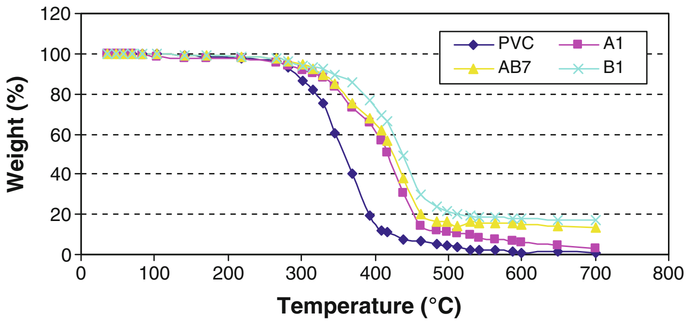

Fig. 2 TGA curves of the composites

Conclusions

The main conclusions drawn from this study are as follows:

- The majority of water absorption occurred during the first 5 days. After that, the percentage of changes is negligible.
- Since composite voids and the lumens of the fibers were filled with water, this improved the penetration of water by the capillary action into the deeper parts of composite. Therefore, the water absorption in WPCs filled with PF was significantly increased.
- With the hybrid composites, the rate of water uptake correlated with percentage weight of WF, lower WF (higher PF) loadings in composites exhibit higher rate of absorption.
- TGA results illustrated that the thermal property of the composites increases after using PF and further increases after addition of WF.

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References

1. Xu Y, Wu Q, Lei Y, Yao F, Zhang Q (2008) Natural fiber reinforced poly(vinyl chloride) composites: effect of fiber type and impact modifier. J Polym Environ 16:250–257
2. Rowell RM (2005) Handbook of wood chemistry and wood composites. Taylor and Francis Group, Boca Raton, FL
3. Clemons C (2002) Wood–plastics composites in the United States: the interfacing of two industries. For Prod J 52:10–19
4. Ashori A (2010) Hybrid composites from waste materials. Polym Environ 18:65–70
5. Das S, Sara AK, Choudhury PK, Basak RK, Mitra BC, Todd T, Lang SJ (2000) Effect of steam pretreatment of jute fiber on dimensional stability of jute composite. Appl Polym Sci 76:1652–1661
6. Saheb ND, Jog JP (1999) Natural fiber polymer composites: a review. Adv Polym Technol 18:351–363