Construction and Building Materials 88 (2015) 159–168

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Characterization of the property changes of extruded wood–plastic composites during year round subtropical weathering

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HIGHLIGHTS

- Increased degradation rates were characterized in subtropical outdoor WPCs.
- Color shaded at the first 90 days and cracking occurred after 90 or 180 days.
- Carbonyl indexes increased continuously to 50–100% in 1 year.
- Morphology of fracture areas confirmed with the experiment results.

ARTICLE INFO

Article history:
Received 1 September 2014
Received in revised form 28 December 2014
Accepted 14 April 2015
Available online 29 April 2015

Keywords:
Mechanical properties
Polypropylene
Weathering
Recycled wood flour
Wood–plastic composites

ABSTRACT

Wood–plastic composites (WPCs) are an emerging material which has been widely applied in outdoor application, but their long-term decomposition behaviors under subtropical weather have not been completely characterized. In this study, WPCs manufactured using recycled wood flour and polypropylene resin were tested for the changes in surface characteristics, physical properties, and mechanical strengths after different time of weathering exposure for one year. Color differential tests showed that significant increase in lightness occurred at the first 90 days of weathering exposure, while notable cracking and mass loss of the components occurred after 90 or 180 days. Carbonyl indexes increased continuously during the testing period for all the tested WPCs. Moisture contents increased most significantly at the initial 90 days of the weathering tests and reached steady states afterward. Increases of water absorption and thickness swelling, and decreases in mechanical properties, were not dramatic except for the samples with excessive-dosed wood contents (i.e. 60% wood flour). The degradation rates of all the parameters were higher than the literature values, which is most likely due to higher sunlight intensity and heavier rainfall in the tested subtropical regions. Changes in morphology of the WPCs surfaces and fracture areas confirmed with the experiment results, and more “pulled-out” fibers were observed for the WPCs after 1 year weathering exposure.

1. Introduction

New generation wood–plastic composites (WPCs) are an environmental-friendly green material created from the “marriage” of the forestry and plastic industries [1,2]. This type of new materials differ from the conventional wood–plastic products, which were mainly composed of virgin thermosetting resins (i.e. phenol- or melamine-formaldehyde resin) and different types/shapes of woods (i.e. sheets, particles, or fibers), and can be manufactured by using recycled wood flour (WF) and recycled plastic resins [3]. Additional values can be created and the service life of wood products can be extended, resulting in significant reduction in environmental impacts and carbon footprint of the waste materials [4]. Furthermore, WPCs have many unique properties which differ significantly from the original materials: WFs can provide physical support to the plastic matrix and increase the mechanical strengths (i.e. stiffness) of the products [5]. Although the biological resistance of WPCs is not as superior as believed by the conventional wisdom [6], the plastic matrix do can provide protection to the wood fiber from moisture: if the wood fiber and plastic can be properly bounded through coupling agents and suitable wood/plastic combination, the resistances of WPCs to water

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http://dx.doi.org/10.1016/j.conbuildmat.2015.04.019

absorption and thickness swelling can be significantly improved [7].

WPCs have found applications in many areas, i.e. automotive industries, windows, doors, and decking [8,9]; and have become very popular in Europe and the United States [1,10]. WPCs have also been widely used in outdoor applications, i.e. public facilities, and industrial or recreational purposes. When applied in the outdoor environment, however, different weathering conditions, i.e. sunlight exposure, rainfall, changes in humidity and/or temperature, could considerably affect the durability of WPCs. Wood is a biomaterial with which the physical and mechanical properties can be significantly affected by the ambient conditions, especially when the plastic matrix cannot completely cover the wood fibers.

Many studies have been carried out to investigate the changes in properties of WPCs under artificial and/or outdoor weathering conditions. Kiguchi, Kataoka, Matsunaga, Yamamoto and Evans [11] investigated the color changes of a WF/PP composites after nature and artificial weathering exposure and showed that color differentials and brightness of WPCs both increased and achieved the maximum value after 3 months weathering exposure. Stark, Matuana and Clemons [12] compared the changes in surface and weathering characteristics of WF/HDPE composites manufactured by different molding processes (i.e. injection, extruded, and planed samples), and showed that color changes were not a function of the manufacture processes but the weathering resistance do reduce with the percent exposure of WF: injection-molded WPC had higher flexural MOE and strength properties after weathering in comparing to WPCs produced after other types of molding processes; the differences were more significant in the first 1000 h, which is possibly due to higher moisture exposure at the period. In a following study the same research group showed that the densities of WPC decreased with the weathering, and observed the damaged surfaces which may cause the reduction of densities through weathering processes [10]. Furthermore, La Mantia and Morreale [13] investigated the photooxidation of the WF/PP WPCs under accelerated weathering conditions, through sophisticated FTIR analysis, and suggested that degradation of plastic is more severe than the degradation of WF in the composite materials.

Among all the previous studies, which many of them were conducted under accelerated weathering conditions [10,12,14–18], the long-term dynamic changes in physical and mechanical properties of the WPCs under outdoor environment were not investigated. Most of the outdoor weathering tests, furthermore, were conducted in the western countries with temperate weather with relatively lower sunlight intensity, humidity, and temperature [19]. The results of accelerated aging may not directly reflect to the outdoor degradation behavior of the WPCs at different testing regions, i.e. in subtropical regions discussed in this study. In addition, the influences and sensitivity of changing WF/PP ratios to weathering durability was not clear. This study, therefore, performed a set of year-round outdoor exposure tests on the recycled waste derived WPCs manufactured after our previous works [7], which investigated the optimal composition of recycled WF/PP WPCs after extruded molding. During different periods of outdoor exposure various types of property analysis were carried out to investigate the effects of changing the WF/PP ratios to color changes, chemical characteristics (i.e. FTIR and carbonyl index analysis), physical and mechanical properties. It was expected by the authors that through the experiments a more clear understanding can be obtained for the long-term weathering behaviors of the WPCs in subtropical regions.

2. Materials and methods

2.1. Materials

Recycled WF, PP, coupling agent, and lubricant were similar to the authors' previous work [7]. The recycled WF was wood processing sawdust provided by Bestwood Co., LTD, Taiwan. The recycled PP (Code ST868 M) pellets was prepared from recycled plastic containers by Shih-Jie Inc., Taiwan. The coupling agent, i.e. Maleic Anhydride Polypropylene (MAPP), and the lubricant, i.e. Zinc stearate ($Zn(C_{18}H_{35}O_2)_2$, ZnSt), were prepared by Plastics Industry Development Center (PIDC), Taiwan. The sawdust was composed of three species, i.e. spruce, pine, and fir (SPF). Before experiment the WF was oven dried at 105 °C until the moisture content decreased to 2% and then screened to remove the large particles by an automated mesh. Wood particles with size smaller than 125 μm (120 mesh screen) were used in this study.

2.2. WPC sample preparation

Extruded WPC samples with four WF/PP ratios were tested, and the compositions of the WPCs were shown in Table 1. The percentages were the mass ratios of WF and PP before compounding. For the four tested samples (i.e., PP-70, -60, -50, and -40), the wood contents in the mixture were gradually increased from 30% to 60%, respectively. The chemical reagents, i.e. the MAPP and ZnSt, at mass contents of 3%, were mixed into the wood–plastic mixture. The actual mass contents of wood and plastics in the WPC were therefore slightly less than the values presented in Table 1. The dosages of the chemical reagents were optimized based the authors' previous works [7] and will not be tested again in this study.

The WF–PP mixtures were mixed with the chemical reagents in a banburing machine for producing the wood–plastic pellets. The total mass of the mixed materials for each compounding series was 3 kg. The mixing rate, temperature, and mixing time were 5.23 rad s^{-1} (50 rpm), 180 °C, and 15 min, respectively. The wood–plastic pellets were oven-dried at 105 °C for 24 h. Extruded molding was performed by a single-screwed extruder with 7 mm screw diameter and 28:1 length to diameter ratio. The extruding temperature was between 150 and 170 °C, and the extruding speed was 0.7–0.8 m min^{-1}, respectively. The cross-section dimensions of the extruded samples were 95 mm wide and 4.5 mm thick, and the length of the samples can vary depending on the requirement.

2.3. Year-round weathering exposure tests

Weathering tests were performed after the Chinese National Standards (CNS) method (CNS 8909). The WPC samples were placed on the rooftop (5th floor) of the main building of the Forestry Department in the National Chung Hsing University, Taiwan (24.7′N, 120.40′E). The mean temperature at the location was 23.8 ± 4.9 °C during the testing period. The maximum observed temperature was 35.7 °C and the highest monthly average was 29.1 °C, and the minimum monthly average temperature was 16.6 °C with the lowest observed temperature 10.1 °C. The average monthly relative humidity (R.H.) was 73.0 ± 2.3%. The maximum monthly average R.H. was 77% and the minimum R.H was 70%. The average solar ultraviolet index (UVI) was 5.7 ± 1.4, with a maximum of 8.2 at July and a minimum of 3.7 at December, respectively. The maximum observed UVI was 11. The monthly rainfall of the testing location was approximately 126.1 ± 94.0 mm, and the rainfall days in a month ranged between 5 and 17 days. The average sunlight exposure time in a month was approximately 149.3 ± 33.8 h.

The samples were mounted on a testing stand with 45° angle to the horizon and facing toward the south for maximizing the sunlight exposure. The samples were harvested for property tests after 3, 6, 9, and 12 months of weathering exposure. The evaluated properties included the surface characteristics, carbonyl index, and the physical /mechanical properties after damages tests. The experiment procedures of the property tests were presented in the following sections in greater details.

Table 1
Material compositions of tested wood–plastic composites.

Sample ID	Wood/plastic ratios (wt%)[a]	
	Wood	Plastic
PP-70	30	70
PP-60	40	60
PP-50	50	50
PP-40	60	40

[a] The ratios are for the wood/plastic mixture before mixing with the other chemical reagents (see text for more details).