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Effects of volatile chemical components of wood species on mould growth susceptibility and termite attack resistance of wood plastic composites

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ABSTRACT

This study mainly aimed at investigating the effects of volatile chemical components of wood species on mould and termite resistance of wood plastic composites (WPC) using artificial accelerated tests. The morphology characterization of surface and fracture of WPC was estimated by SEM and digital instrument. Volatile chemical components of wood species extractives were analyzed by GC–MS. The results indicated that the sequences of mould resistance of WPC were ranked as: *Cunninghamia lanceolata* and *Melaleuca leucadendra* (level 0) > *Eucalyptus grandis* × *Eucalyptus urophylla* (level 1) > *Pinus massoniana* (level 2) > *Liquidambar formosana* and *Ricinus communis* (level 4). The sequences of termite resistance of WPC were ranked as: *C. lanceolata* (level 1, ML = 4.52%) > *M. leucadendra* (level 1, ML = 5.73%) > *E. grandis* × *E. urophylla* (level 1, ML = 6.48%) > *L. formosana* (level 2, ML = 6.72%) > *P. massoniana* (level 2, ML = 7.08%) > *R. communis* (level 3, ML = 10.40%). It was also suggested that 8-propoxy-cedrane, cedrol, α-cedrene and β-cedrene in *C. lanceolata*, 2,3-dihydro-2,2-dimethyl-3,7-benzofurandiol, 3-demethylcolchicine and squalene in *M. leucadendra*; 2,3-dihydro-2,2-dimethyl-3,7-benzofurandiol and stigmast-4-en-3-one in *E. grandis* × *E. urophylla* were potentially crucial to provided positive effects on biodegradation resistance. Longifolene, caryophyllene and α-pinene in *P. massoniana*; 4-hydroxy-3,5-dimethoxy-benzaldehyde, 3,5-dimethoxy-4-hydroxycinnamaldehyde and cinnamyl cinnamate in *L. formosana*; 5-hydroxymethylfurfural and 1,6-anhydro-β-D-glucopyranose in *R. communis* led to the opposite results.

Introduction

Wood plastic composites (WPC) are mainly produced by thermoplastic resin (polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC)) and biomass fibre from agricultural and forestry residues (Clemons, 2002; Hamzeh et al., 2012; Hosseinaei et al., 2012; Kaewkuk et al., 2013; Wei et al., 2013; Zolfaghari et al., 2013). Under the global background of continuously declining forestry resources, increasing price of petroleum and pervasive consciousness of ecological concerns, WPC has been well acknowledged as an alternative innovative engineering material for residential and industrial constructions, such as landscaping facilities, fencing, flooring, cladding, siding, exterior decking and railing material, owing to its intrinsic advantages of low maintenance and environmentally friendly characteristic compared to chemically treated solid wood and traditional wood-based composites (MDF, PB and plywood) (Kartal and Green, 2003; Karimi et al., 2007; Fabiyi and McDonald, 2010; Zhang, 2014).

In the early stage of WPC application, it was assumed that thermoplastic resin can completely encapsulated wood flour providing protection against biological damage (Defoirdt et al., 2010; H'ng et al., 2011; Segerholm et al., 2012a,b). As the growth of service time of WPC, it gradually began to be concerned that although there was a superior decay resistance for WPC than solid wood, initial biological degradation including microorganisms (wood decaying fungi and mould) as well as harmful biological species (termite) can occur when the outmost thin layer of WPC was damaged under favourable exterior environment

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(Chaochanchaikul et al., 2013), such as ultraviolet (UV) radiation, temperature, oxygen and moisture (Mankowski and Morrell, 2000; Fabiyi et al., 2011; Naumann et al., 2012; Segerholm et al., 2012b). The physical and mechanical properties of WPC as well as the fibre–matrix interactions would adversely be affected, which may cause some failures and accidents of engineering items.

Traditionally, "wood" component of WPC is just considered to be common fillers with almost the same properties. Most researchers paid their more attention to control the moisture absorption and interface adhesion of WPC to improve the resistant capacities of living organisms. There are only few focuses on the selection of wood species. However, different contents and types of volatile chemical components exist in various wood species (Vazquez et al., 2008). Some of them contain high toxic and volatile substances, which will result in a passive or negative effect on the susceptibility and resistance of living organisms (Rowell, 1984). In recent years, studies indicated that using different wood species led to the various biodegradation properties of WPC (Escobar, 2008; Kim et al., 2008). Dawson-Ahdoh et al. (2004) concluded that the mould colonization of PVC-based WPC made by maple flour was more severe than the one made by pine flour. Fabiyi et al. (2011) investigated the durability of white rot for different PE-based WPC made by poplar, Douglas-fir, black locust, white oak, and ponderosa pine, which demonstrated that poplar and pine were more suitable for WPC production with the low attacking chance by white rot. Lomeli-Ramirez et al. (2009) indicated that PP-based WPC containing either maple or oak were more susceptible to fungal attack than those containing pine. In addition, Chow et al. (2002) also found that PE-based WPC made by *Parthenium argentatum* fibre, *Parthenium incanum* fibre and *Parthenium tomentosum* fibre have excellent termite resistant properties corresponding to mass loss rate of 7%, 6% and 5% by contrasting the one made by pine fibre (mass loss rate of 40%). Up to now, there is no available information about the effects of wood species and the relation of volatile chemical substances in different wood species on mould growth susceptibility and termite attack resistance of PVC-based WPC.

Thus the aim of this study was to firstly examine the effects of volatile chemical components of wood species on mould growth susceptibility and termite attack resistance of PVC-based WPC. The natural mould proof and termite resistant properties for various wood species were examined using artificial accelerated tests and scanning electron microscopy (SEM). The six wood species selected were *Cunninghamia lanceolata*, *Pinus massoniana*, *Eucalyptus grandis* × *Eucalyptus urophylla*, *Melaleuca leucadendra*, *Liquidambar formosana* and *Ricinus communis*. Meanwhile, in order to investigate the relevance between volatile chemical substances of wood species and natural biodegradation resistances, the volatile chemical components of different wood species were extracted using Soxhlet extraction and analyzed by gas chromatograph-mass spectrometer (GC–MS).

Materials and methods

Materials

Six wood species were used as wood flour: *C. lanceolata*, *P. massoniana*, *E. grandis* × *E. urophylla*, *M. leucadendra*, *L. formosana* and *R. communis*, they were obtained from Zengcheng Baigao Manufacturing Ltd. Co., China. Five mould fungi (*Aspergillus niger*, CGMCC 3.5487; *Chaetomium globosum*, CGMCC 3.3601; *Penicillium funiculosum*, CGMCC 3.3875; *Aureobasidium pullulans*, CGMCC 3.837 and *Trichoderma viride*, CGMCC 3.2941) were provided by Guangdong Institute of Microbiology. Termites (*Coptotermes formosanus* Shiraki) were provided by Guangdong Entomological Institute. PVC (DG-800) was supplied by Tianjin Dagu Chemical Ltd. Co., China. To complete the formulation, the other additives including chlorinated polyethylene (CPE), acrylamide (ACR), calcium zinc stabilizer and paraffin wax were bought from local chemical companies.

Processing of WPC

Six wood species (*C. lanceolata*, *P. massoniana*, *E. grandis* × *E. urophylla*, *M. leucadendra*, *L. formosana* and *R. communis*) were selected on the tests. Firstly wood was sliced, smashed and sieved to provide the 40–60 mesh wood flour (WF), then WF was dried at 105 °C for 72 h in an oven prior to blending. The polymer matrix used in this study was polyvinyl chloride (PVC), both WF (100 phr) and PVC (100 phr) were mixed in a high speed blender (SHR-10A, Zhangjiagang, China) at 1800 rpm for 8 min. Other additives including calcium–zinc heat stability (4 phr), chlorinated polyethylene (3 phr), acrylamide (3 phr) and paraffin wax (0.8 phr) also were added and mixed at 105 °C for 10 min. Subsequently the mixture was extruded as a shape of sheet by conical twin-screw extrusion (LSE-35, Guangzhou, China) with a screw diameter of 40 mm and length to diameter of 13:1 corresponding to the temperature of 130, 145, 165, 180 and 178 °C from hopper to die zone with rotation speed being 25 rpm.

Mould resistance test of WPC

Mould resistance test of WPC was conducted according to GB/T 24128 (2009) with the following steps. Firstly, potato dextrose agar and nutrient solution of salt were prepared according to the standard contents. Five mould fungi (*A. niger*, *C. globosum*, *P. funiculosum*, *A. pullulans* and *T. viride*) were selected for use. The culture of each fungus was initially inoculated on potato dextrose agar in petri plates at 28 °C and relative humidity of 85% until the whole surface of the petri plate was covered with fungal hyphae. Then a few spores were gently scraped using nichrome inoculating wire and poured into the test tube with 10 ml sterile water as spore suspension. Subsequently the suspension was put into Erlenmeyer flask with sterile water and solid glass beads, the suspension was vigorously vibrated to separate spores and break the spore clumps. Then it was filtered and centrifuged at a rotation speed of 4000 rpm to get the precipitate. Finally the five types of mould mixing suspension were prepared by putting into each types of suspension of mould spore at the same addition amount. This suspension was then transferred to a 25 ml spray bottle and used as the source of fungal inocula for test.

WPC specimens (30 mm × 30 mm × 5 mm) in the petri plates were dried and sterilized prior to tests. The surface of each sample was sprayed with equal amount of mixing mould inocula suspension and put on the cover. Petri plates were kept at 28 ± 2 °C and 75–80% relative humidity for 4 weeks. The level of mould was estimated referring to GB/T 24128 (2009). Meanwhile, surface and fracture morphology of specimens were observed using a SEM (Hitachi S-3000N, Philips, Japan) with an accelerating voltage of 25 kV. The specimens were dried and sputter coated with a thin layer of gold before observation.

Termite resistance test of WPC

Termite resistance test of WPC was carried out in accordance with GB/T 18260 (2000) as well as referring to the previous literature (Tascioglu et al., 2013). The samples (30 mm × 30 mm × 5 mm) were randomly selected from each WPC group for termite tests. Only normal specimens (without groove) were used in the tests. WPC specimens were placed at the centre of