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Potential use of decayed wood in production of wood plastic composite

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ABSTRACT

This study investigated the mechanical and thermal properties of hot press molded wood plastic composite (WPC) panels produced from different amounts (30, 40, or 50% weight) of Scots pine (*Pinus sylvestris* L.) wood decayed by brown-rot fungi and polypropylene with coupling agent (maleic anhydride grafted polypropylene, 3 wt%). The results were compared with the properties of WPCs produced with the sound wood. The holocellulose content of the decayed wood was found to be significantly lower than that of the sound wood. Although the flexural and tensile properties of WPCs produced with the decayed wood flour were lower than those of the WPCs produced with the sound wood flour, their thermal stabilities were better at the wood flour levels of 40 wt% and 50 wt%. The weight loss of the WPCs produced with a high amount of decayed wood was lower than that of the WPCs produced with the sound wood, their enthalpy and crystallization degree were higher than those of the WPCs produced with the sound wood as well.

1. Introduction

The term wood plastic composite (WPC) refers to any composite material that contains wood and thermoplastics. WPC products have commonly substituted for solid wood in today's building structures over the last decade (Ashori et al., 2013). The objective of WPC development is to produce a product with performance characteristics that combine the positive attributes of wood and plastic. Significant advantages of WPC are their high durability and renewability, low maintenance, acceptable relative strength and stiffness, less abrasive wear to processing equipment, environmental friendly, and similar as wood feature (El-Haggar and Kamel, 2011; San et al., 2008).

Wood decay is a deterioration of wood by primarily enzymatic activities of microorganisms (Srivastava et al., 2013). Brown-rot decay is the most common and most destructive type of decay of wood in use. The most serious kind of microbiological deterioration of wood is caused by fungi because they can cause rapid structural failure (Green III and Highley, 1997). Brown-rot fungi destroy wood by selectively degrading the hemicelluloses and cellulose (holocellulose) without extensively changing the lignin (Flournoy et al., 1991). Because of the attack on hemicellulose and cellulose, the strength properties of brown-rot decayed wood decrease quickly, even in the early stages (Rowell, 2012). The lignin component also presents a barrier to wood decay because lignin is a complex aromatic polymer that encrusts the cell walls, preventing access of enzymes to the more easily degradable cellulose and hemicelluloses (Green III and Highley, 1997). The removal of lignin as a hydrophobic component tends to favor an increased water absorption and thickness swelling of WPCs (Kord and Hosseinihashemi, 2014). Previous studies reported water absorption and thickness swelling of lignocellulosic filled polypropylene composites increased with growing time of exposure to the brown-rot fungi (Kord and Hosseinihashemi, 2014; Hosseinihashemi et al., 2011).

Many countries face the problem of lack of woody raw material in wood composite industry since most of their forested areas are unproductive. WPC industry has been rapidly increased in many countries in last decade. Growing demand for WPCs in building industry has led to continuous efforts to find new lignocellulosic resources. Sound wood is used in the production of wood-based panels such as particleboard and fiberboard while decayed wood has no economic value. This was because the chips produced from decayed wood are highly undesired, due to reduced yield of pulp and its diminished quality. Moreover, wood powder or fines is obtained from the decayed wood instead of particles with uniform size and shape during the chipping process. For this reason, wood decayed by fungi is not desirable raw material for wood-based

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panel industry. The decayed wood is usually used as firewood. However, the decayed wood may play an important role as filler for thermoplastic composite industry. Use of inexpensive alternative sources of sound wood is important for the long-term sustainability of the WPC industry. Therefore, WPC industry may be the most efficient industry to use decayed wood.

Although there have been a number of studies concerning the utilization of sound wood flour in WPC (Ayrilmis and Jarusombuti, 2011; Ayrilmis et al., 2011; Ayrilmis and Kaymakci, 2013; Bajwa et al., 2011; Bazant et al., 2014), the potential use of decayed wood in the production of WPC has not been studied yet in the literature. The main objective of this study was to investigate mechanical and thermal properties of WPCs produced from different amounts of decayed wood flour and polypropylene with coupling agent and compare with the properties of the WPC panels containing the sound wood.

2. Materials and methods

2.1. Wood material

Felled Scots pine (*Pinus sylvestris*) tree decayed by brown-rot fungi was obtained from plateau of Kafkasor, 8 km away from Artvin province on the Black Sea coast in the north-eastern corner of Turkey. For comparison with the decayed tree, sound Scots pine tree was harvested in the same location. The breast diameters of the decayed and sound trees were about 40 cm. The discs (10 cm thick) were taken from 40 cm and 2.40 cm heights of the decayed and sound logs based on the ground level.

The wood particles were obtained from the discs using a laboratory type drum chipper with three knives. The wood particles of sound wood and decayed wood were separately proceeded. The wood particles were then processed by using a laboratory grinder. A vibratory sieve shaker (Fritsch Analysette) was used to obtain 60 mesh size wood flour for the WPC production and 40–100 mesh size wood flour for the chemical analysis. Before the WPC production, the wood flour was dried in a laboratory oven at 102 °C for 24 h to a moisture content of 0–1% based on the oven-dry weight of wood.

2.2. Polymer matrix and coupling agent

The polypropylene (PP) (melt flow index: 230 °C/2.16 kg = 3.2 g/10 min, density: 0.91 g/cm^3) produced by Borealis AG in Austria was used as the polymer matrix. The coupling agent, maleic anhydride-grafted PP (MAPP-Optim-425, melt flow index: 190 °C, 2.16 kg = 120 g/10 min, density: 0.91 g/cm^3), was supplied by Pluss Polymers Pvt., Ltd., in India.

2.3. Preparation of hot press molded WPC panels

Different portions of the wood flour, PP, and MAPP granulates were processed in a co-rotating twin-screw extruder with a length-to-diameter (L/D) ratio of 30:1. The barrel temperatures of the extruder were controlled at 170, 180, 185, and 190 °C for the zones 1, 2, 3, and 4, respectively. The temperature of the extruder die was held at 200 °C. The extruded strand passed through a water bath and was subsequently pelletized. The pellets were dried to the moisture content of 0.5–1% in a laboratory oven before the hot-press molding. The pellets were compression molded in a Carver hydraulic laboratory press. The hot-press temperature, pressure, and pressing time were 170 °C, 2.5 N/mm^2, and 5 min, respectively. At the end of the hot pressing cycle, the WPC panel was moved from the hot press into a press at room temperature for cooling. A 3 mm thick WPC panels were then trimmed to a final size of 130 mm × 130 mm. A total of 12 experimental WPC panels, 2 for each type of WPC panel, were produced. The specimens were conditioned at a temperature of 23 °C and relative humidity of 50% according to ASTM D 618. The density values of the specimens varied from 0.94 to 1.02 g/cm^3. The experimental design is presented in Table 1.

Table 1
Experimental design.

WPC type	Sound wood flour (%wt)	Decayed wood flour (%wt)	Polypropylene (%wt)	MAPP (%wt)
A	30	–	70	3
B	40	–	60	3
C	50	–	50	3
D	–	30	70	3
E	–	40	60	3
F	–	50	50	3

MAPP: maleic anhydride grafted polypropylene.

2.4. Chemical analysis of sound and decayed wood specimens of Scots pine

The preparation of wood specimens for chemical analysis was performed according to TAPPI T 264 cm-07 (2007) standard. Alcohol–benzene, hot and cold water solubility, and solubility in dilute alkali (1% NaOH) were determined according to TAPPI T 204 cm-07 (2007), TAPPI T 207 cm-08 (2008), TAPPI T 212 om-12 (2012), respectively. Holocellulose, α-cellulose, and lignin contents of wood specimens were determined by the chlorite method (Wise and Karl, 1962), TAPPI T 203 cm-09 (2009), and TAPPI T 222 om-11 (2011), respectively. Ash content was analyzed by TAPPI method, 2012a; Tappi test method T 211 om-12 (2012).

2.5. Determination of mechanical properties of WPC panels

The flexural tests were conducted in accordance with ASTM D 790 (2010) using a Lloyd universal testing machine at a rate of 1.3 mm/min crosshead speed. The dimensions of the test specimens were 3.5 mm × 13 mm × 128 mm. The tensile tests were conducted according to ASTM D 638 (2010). The tensile specimens (dog-bone shape) were tested in a universal testing machine with a crosshead speed of 5 mm/min in accordance with ASTM D 638 (type III tensile testing bar). Seven specimens were tested for the tensile and flexural properties of each type of WPC panel.

2.6. Thermal analysis of WPC panels

Melting and crystallization behavior of the WPCs were studied in a heat-flux type differential scanning calorimeter (DSC) (PerkinElmer DSC 8000) according to ASTM International, 2008a; ASTM D3418 (2008). To determine the influence of the increasing amount of the decayed wood or sound wood on the thermal properties of WPC, test sample of 5–6 mg of each type of WPC was placed in an aluminum pan and then heated from 35 to 250 °C at a heating rate of 10 °C/min under the nitrogen flow.

The thermogravimetric analysis (TGA) of each type of WPC was carried out in an inert environment of gas nitrogen flowing 20 mL/min using a PerkinElmer STA 6000 analyzer. The specimens having a weight between 17 mg and 20 mg were heated from 50 to 600 °C at a heating rate of 20 °C/min. The corresponding weight loss (%) and its derivative weight loss (min/%) were recorded.

2.7. Statistical analysis

An analysis of variance, ANOVA, was conducted ($p < 0.01$) to evaluate the effect of the decayed wood on the mechanical properties of the WPCs. Significant differences among the average values