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Table of Contents

Wood Panels Composites
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Mechanical Performance of Wood Plastic Composites Containing Decayed Wood

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Abstract

This study investigated the potential use of the decayed wood in the manufacture of wood plastic composite (WPC) panel. Scots pine (*Pinus sylvestris*) sound wood and decayed wood (brown-rot fungi) were used as wood material. Three levels of 30%, 40%, and 50% of sound wood and decayed wood, based on the composition by weight, were mixed with the polypropylene with 3% (based on weight) maleic anhydride grafted PP (MAPP) as a coupling agent. The compound pellets were prepared from twin screw co-rotating extruder. The WPC panels were produced by hot-press molding technique. The chemical properties of sound wood and decayed wood were investigated. The flexural and tensile properties of 3 mm thick WPC panels were determined according to ASTM standards. Although the holocellulose content of the decayed wood was significantly lower than that of the sound wood, there was no great difference between the flexural and tensile properties of the WPC panels containing decayed wood or sound wood. Based on the findings obtained from the present study, it can be said that a certain amount of the decayed wood can be incorporated into the composition of WPCs containing sound wood.

***Keywords*:** wood plastic composite, decayed wood, mechanical properties.

Introduction

Wood-plastic composite (WPC) is composite materials made of wood fiber/wood flour and thermoplastic(s) (includes PE, PP, PVC etc.). WPC has gained popularity over the last decade especially with its properties and advantages that attracted researchers such as: high durability, low maintenance, acceptable relative strength and stiffness, fewer prices relative to other competing materials, and the fact that it is a natural resource (El-Haggar et al. 2011).

Wood decay is a deterioration of wood by primarily enzymatic activities of microorganisms. 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. Brown-rot fungi destroy wood by selectively degrading the hemicelluloses and cellulose without extensively. changing the lignin (Flournoy et al. 1991). The rapid depolymerization of the wood carbohydrates is reflected by the substantial increase in alkali volubility products and the rapid decrease in strength properties of brown rotted wood. 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. In addition to these points, wood often contains potentially fungitoxic compounds, which are deposited in the heartwood (Green and Highley 1997).

Many countries face the problem of lack of woody raw material in forest products industry since most of their forested areas are unproductive. Sound wood can be used in the wood composite industry while decayed wood has no economic value in the wood composite . Although there have been a number of studies concerning the use of sound wood flour on the mechanical properties of WPC (Ayrilmis and Jarusombuti 2011, Ayrilmis et al. 2011, Ayrilmis and Kaymakci 2013), there is still no any study on the potential use of decayed wood in the manufacture of thermoplastic composites in the literature. The main objective of this study was to investigate potential use of decayed wood in the manufacture of WPC panel and compare the mechanical properties of the WPC panels with the WPC panels containing sound wood.

Materials and Methods

Materials

Wood material

Felled Scots pine (*Pinus sylvestris*) trees decayed by brown-rot fungi were supplied from plateau of ***Kafkasor***, 8 km away from ***Artvin province*** on the Black Sea coast in the north-eastern corner of the country, on the border with Georgia. The sound Scots pine trees were 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 the 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 decayed and sound wood discs using laboratory type drum chipper with three knives. The wood particles were then processed by using a laboratory ***Fritsch*** grinder. A vibratory sieve shaker (Fritsch Analysette) was used to obtain 60 mesh size wood flour for the WPC manufacture and 40-100 mesh size wood flour for the chemical analysis of sound and decayed wood. The wood flour used in the WPC manufacture 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. The dried wood flour was stored in a plastic bag.

Polymer matrix and coupling agent

The polypropylene (PP) (MFR/230°C/2.16 kg = 3,2 g/10 min, density: 0.91 g/cm^3, isotactic index: 97.5%) produced by Borealis AG in Austria, was used as the polymeric material. The coupling agent, maleic anhydride-grafted PP (MAPP-Optim-425, MFI/190°C, 2.16 Kg = 120 g/10 min, density: 0.91 g/cm^3), was supplied by Pluss Polymers Pvt. Ltd. in India.

Preparation of hot press molded WPC panels
The wood flour, polypropylene, and MAPP granulates were processed in a 30 mm 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 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 stored in a sealed container and then dried to the moisture content of 1-2% in a laboratory oven before the hold press molding. The pellets were compression molded in ***Carver*** hydraulic lab press. Press temperature, pressure, and press time were 170°C, 25 bar, and 5 min, respectively. At the end of the hot pressing cycle, the panel was moved from the hot press into a press at room temperature for cooling. Ten 3 mm thick panels were then trimmed to a final size of 130 mm × 130 mm. A total of 12 experimental panels, 2 for each type of panel, were manufactured. Finally, the specimens were conditioned at a temperature of 23 °C and relative humidity (RH) of 50% according to ASTM D 618. Air-dry density values of the specimens varied from 0.93 to 1.02 kg/m^3. The raw material formulations used for the WPCs are presented in Table 1.

Table 1. Experimental design.

WPC code	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.

Chemical analysis of sound and decay wood specimens of Scots pine

For the determination of the chemical properties of the sound wood and decayed wood, the preparation of the test specimens was carried out according to TAPPI T 257 cm-85 standard. Alcohol-benzene, hot and cold water solubility's, and solubility in dilute alkali (1% Na OH) were determined according to TAPPI T 204 cm-97, TAPPI T 207 cm – 99, TAPPI T 212 cm – 98, respectively. Holocellulose and α-cellulose, and lignin contents were determined by the chlorite method (Wise and Karl, 1962), TAPPI T 203 cm – 99, and the ***Runkel method*** (***Runkel*** and ***Wilke*** 1951), respectively. Ash content was analyzed by Tappi T 211 om-93.

Determination of mechanical properties

The flexural tests were conducted in accordance with ASTM D 790 using a Lloyd testing machine at a rate of 1.3 mm/min crosshead speed. Dimensions of the test specimens were 3.5 mm x 13 mm x 128 mm. The tensile tests were conducted according to the ASTM D 638. Tensile specimens were tested with a crosshead speed of 5 mm/min in accordance with ASTM D 638. Seven specimens were tested for the tensile and flexural properties of each composite formulation.

Results and Discussion

The results of chemical analysis of sound wood and decay wood of Scots pine are presented in Table 2. Solubility in cold water, hot water, and dilute alkali (1% NaOH) of the decayed wood were considerably higher than those of the sound wood. The lignin content in the decayed wood increased from 28.24 to 50.75% as the sound wood degraded by brown-rot fungi while the α-cellulose content decreased from 43.15 to 14.42%.

Table 2. The results of chemical analysis of sound wood and decay wood of Scots pine.

Chemical analysis	Unit	Decayed wood	Sound wood
Solubility in cold water	%	5.49	3.12
Solubility in hot water	%	8.57	4.22
Solubility in dilute alkali (1% NaOH)	%	54.97	16.41
Solubility in alcohol-benzene	%	16.12	5.81
Lignin	%	50.75	28.24
Holocellulose	%	35.16	73.27
α- cellulose	%	14.42	43.15

The results of flexural and tensile tests are presented in Table 3. As excepted, the strength values of the WPCs containing decayed wood were considerably lower than those of the WPCs containing sound wood. This was mainly due to the chemical changes of the wood degraded by brown-rot fungi. As shown in Table 2, the holocellulose of the decayed wood was found to be 35.16% while it was found to be 73.27% for sound wood.
Cellulose is primarily responsible for the strength of the wood fiber; therefore, reducing the length of the cellulose molecules (degree of polymerization) would cause a reduction in macro-strength properties of wood (Sweet and Winandy 1999). The brown-rot fungi accelerate depolymerization of the cellulose by breaking down the long chain cellulose (crystalline structure) to shorter chain. Depolymerization and shortening of the cellulose polymer adversely affect flexural and tensile properties of the wood.

There was no great difference between the flexural and tensile properties of the WPC panels containing decayed wood or sound wood. For example, at the same wood flour content (50 wt%), the flexural strength and modulus of the WPC containing 50 wt% sound wood was determined as 24.8 N/mm^2 and 3784 N/mm^2 while they were found to be 21.5 N/mm^2 and 3349 N/mm^2 for the WPCs containing 50 wt% decayed wood, respectively. Similar results were found for the tensile strength and modulus. Although the flexural and tensile strength of the WPCs containing sound wood or decayed wood decreased with increasing wood flour content, the flexural and tensile modulus of the WPCs increased. The flexural and tensile modulus of the WPCs increased by 15.9% and 16.5 as the amount of the sound wood content increased from 30 to 50 wt% in the WPC. These properties were found to be 13.9% and 12.7% for the WPCs containing decayed wood.

Table 3. Density and mechanical properties of the WPC panels.

WPC code[1]	Density (g/cm^3)	Flexural strength (N/mm^2)	Flexural modulus (N/mm^2)	Tensile strength (N/mm^2)	Tensile modulus (N/mm^2)
A	0.97 (0.01)	33.3 (2.3) a	3263 (407)	21.0 (1.1)	2779 (485)
B	1.00 (0.01)	29.7 (1.2) b	3510 (141)	18.0 (0.9)	3063 (554)
C	1.02 (0.02)	24.8 (1.2)	3784 (157)	16.7 (1.3)	3239 (381)
D	0.94 (0.02)	28.6 (1.9)	2940 (128)	17.9 (2.0)	2577 (400)
E	0.95 (0.01)	24.4 (2.2)	3163 (372)	14.7 (3.1)	2769 (347)
F	0.98 (0.02)	21.5 (1.9)	3349 (185)	12.3 (1.3)	2906 (580)

[1] See Table 1 for WPC panel formulation. The values in the parentheses are standard deviations.

Conclusions

This study investigated the potential use of the decayed wood in thermoplastic composites as reinforcing filler. Although the holocellulose content of the decayed wood was significantly lower than that of the sound wood, there was no a great difference between the flexural and tensile properties of the WPC panels containing decayed wood or sound wood. Based on the findings obtained from the present study, it can be said that a certain amount of the decayed wood can be incorporated into the WPCs made using sound wood.

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