Mokchae Konghak 34(5) : 79~87, 2006

Feasibility of Value-added Utilization of Ash Trees Infested with Emerald Ash Borer*[1]

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ABSTRACT

Value-added utilization of the disposed ash trees due to the infestation by Emerald Ash Borer (EAB) was explored by converting them into particleboards (PBs) and wood-plastic composites (WPCs). The experimental result showed that PB panels could be successfully manufactured from the ash wood but compaction ratio need to be higher than 1.3 in order to meet the standard requirements listed by American National Standards Institute (ANSI). Ash wood plastic composites with high density polyethylene (HDPE) and polypropylene (PP) were also prepared with additives by extrusion. Physical and mechanical properties of ash wood plastic composite compared favorably to those made of pine and maple.

Keywords : emerald ash borer, particleboard, wood plastic composite, compaction ratio, density profile

1. INTRODUCTION

In summer 2002, exotic wood-boring beetles were found in southeastern Michigan and Windsor, Ontario infesting and killing ash trees (*Fraxinus* spp.). The beetles identified as *Agrilus planipennis* Fairmaire (Emerald Ash borer (EAB)), infested three major ash trees namely white ash (*F. americana*), green ash (*F. pennsylvanica*) and black ash (*F. nigra*) trees in urban and forested areas and impacted more than 600 million trees in southeastern Michigan (Michigan Department of Agriculture, 2003). Since its invasion, economic loss in Michigan estimated to $11.6 million and spread of EAB beyond Michigan could cause up to $60 billion loss in ash related economy in nationwide (USDA AIPHIS, 2003).

To contain and control the EAB infestation, EAB eradication program has been established and as a part of the program, dead and dying ash trees have been cut and disposed at designated sites (Michigan Department of Agriculture, 2004). As of April 2004, the Michigan Department of Agriculture estimated that 83,000 tons of ash wood had been processed at the marshalling yards in southeastern Michigan. If converted into dry wood, it is estimated that 28,000 to 42,000 tons of ash wood can be obtained assuming 100~200% moisture content in ash tree. Those are mostly city trees and trees from private yards

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*1 Received on May 16, 2006; accepted on June 13, 2006

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and lawns. This amount does not include tens of thousands of trees that were cut as part of eradication projects. It was reported that nearly 5.8 milion ash trees are dead or dying out of 11.6 million ash trees occur in the infested area of southeast Michigan (USDA APHIS, 2003). Tremendous number of dead or dying ash trees is going to be removed from landscape and forest to control and ultimately eradicate EAB. Therefore, it is evident that in addition to 83,000 tons of already-processed ash wood, staggering amount of ash trees is to be disposed in near future. Some of the disposed ash logs are being transformed into wood products such as railroad ties in order to mitigate the amount of waste material. Most of the remaining ash materials are chipped and transported to a cogeneration plant, where they are used to produce electricity. However, there is no attempt to add more values on these natural resources. It is necessary to develop methods to convert overwhelming amount of ash trees into value added products. If not, these valuable natural resources turn into waste and may cause serious disposal problem.

There are alternative ways to add value in these ash trees. One of the most value-added utilizations is to converts them into high value products such as wood-based composites and wood-plastic composites. Although ash has been used for solid wood products, it is difficult to use EAB infested ash for solid wood because of the quarantine regulations, which prohibit movement of ash trees, logs or untreated ash lumbers with bark. In addition, it may take additional cost and time to treat ash logs or lumbers with insecticide to control EAB adult and larvae. McCullough and co-workers reported that no EAB larvae are founded when infested ash trees are grinded into chips with less than 25.4 mm size (McCullough *et al.*, 2003). Also quarantine regulations allow movement of uncomposted ash chips less than 25.4 mm. Since particleboard (PB) and wood plastic composites need small wood particles, ash chips can be transported to local mills and readily used as raw material with little additional process. EAB and larvae also could be easily destroyed during the composite manufacturing process such as grinding and drying.

In general, PBs are manufactured using low density wood species such as pine and aspen. There have been several research works regarding utilization of high density wood species such as oak in flakeboard manufacturing but no research has been reported in utilizing ash trees as a raw material for PB manufacturing (Larmore, 1959 ; Vital *et al.*, 1974 ; Hse, 1975). Similarly, WPCs are generally manufactured using pine, maple, and oak but little has been known about manufacturing WPCs out of ash. Therefore, the present study focuses on manufacturing of PB and WPC from ash wood. Various mechanical and physical properties of the composites are compared to those made of conventional species. The objectives of this project are thus to demonstrate the feasibility of manufacturing PB and WPC from EAB infested ash trees.

2. MATERIALS and METHODS

2.1. Materials

Aspen strands were hammer milled and screened with three types of Tyler meshes; 10, 25, and 100. EAB infested ash trees with bark were chipped less than 25.4 mm size and transported to the Michigan State University, Wood Composite Lab. There was no effort to separate bark from wood. The ash chips were dried for 72 hrs at 105°C, conditions which are above the normal temperature required to kill the beetles and larvae. The particles were produced from the dried ash chips via grinding in a hammer mill with 6.34 mm mesh size. The ground wood was then screened with a series of meshes (10, 25, and 100 Tyler mesh). Both ash and aspen particles of -2 mm / +710μm (-10 / +25 Tyler mesh) were used for PB manufacturing, while those of -710 μm / +147 μm (-25 / +100 Tyler mesh) were used for WPC manufacturing. Pine and maple flours of 425 μm (40 Tyler mesh) were also used for WPC manufacturing as comparison. All the particles were oven dried at 105°C for 24 hrs before being used as PB and WPC making. Commercial UF resin has been obtained from Dynea (Springfield, OR). Solid content, viscosity and pH of the resin were 64.9%, 185 cPs at 20°C, and 8.56 respectively.

Commercial grade flake type high-density polyethylene (HDPE) and polypropylene (PP) were obtained from BP Solvay polyethylene North America (Houston, TX) and Rohm Haas (West Philadelphia, PA), respectively and used for wood-plastic composites. The melt flow index was 0.49 g/10 min for HDPE and 0.7 g / 10 min for PP. Lubricants (TPW104 and TPW113) obtained from Struktol (Stow, OH) and coupling agents (E43, G3003, and G2608) obtained from Eastman Chemical Company (Kingsport, TN) were also used for manufacturing WPCs.

2.2. Particleboard Manufacturing

For each species, three 406×406×9.5 mm panels with target density of 650 Kg / m^3 were formed. Particles were blended with the UF resin in a rotating drum blender using atomizing spray gun and formed into a mat. The mat was then hot pressed for 5 minutes at 149°C. The initial pressure of 6.9 MPa was first applied for 15 sec followed by 4.5 MPa which continued for 4 minutes and then decreased to 0 MPa over 45 seconds before press opening. The hot pressed panels were cooled and conditioned at 20°C 65% relative humidity (RH) before trimmed to 330mm square and cut into specimens for various testing. Three flexural test samples and five IB samples were cut from each board and three repicate boards were manufactured. After flexural test, thickness swelling and water uptake test samples were prepared from the flexural test samples. Screw holding test samples were also manufactured with 25.4 mm thickness using above mentioned manufacturing conditions.

2.3. Evaluation of Particleboard Properties

Mechanical and physical properties such as modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) strength, thickness swelling (TS), water absorption, and screw-holding properties for the PBs were evaluated according to the ASTM 1037-99 (ASTM, 1999). All specimens were conditioned at 65% RH and 20°C prior to testing. The mechanical properties tests such as bending, IB, and screw holding tests were performed on a computercontrolled testing machine (Model 4260, Instron Inc. Canton, MA). The speed of the crosshead was set based on the ASTM standards. Density profile of the PBs through the thickness was also measured. 5 specimens from each batch were collected and density profile was measured with Density Profiler (QDP-01X, QMS Inc., Oak Ridge, TN) and average density profile was calculated.

2.4. WPC Manufacturing and Property Evaluation

Dried wood flours, thermoplastic polymer and additives were mixed in a Papenmeier high intensity mixer for 10 minutes. The mixture was then extruded with a 32 mm conical counter-rotating twin-screw extruder (C.W. Brabender Instruments Inc.) with a length to diameter (L/D) ratio of 13:1, driven by a 5.6 kW (7.5 HP) Intelli-Torque Plasti-Corder Torque Rheometer®. A die that produced 25.4×9.5 mm profile was used. Ash/HDPE and ash/PP composites with lubricant only and with lubricant and coupling agents were manufactured. The temperature of the three zones and die in the extruder and processing speed were selected based on previous work with other species such as pine and maple (Maurice and Matuana, 2004). The manufacturing conditions for different types of WPCs are shown in Table 3. Extruded profiles were cooled in a cold water cooling system immediately after leaving die. The profiles were then cut into 190 mm length and conditioned at 65% RH and 20°C before testing. Ten samples per formulation were obtained for flexural test, which was performed according to ASTM D790 -02 (ASTM, 2002) with above-mentioned testing machine (Model 4260, Instron Inc. Canton, MA). The samples used for notched Izod impact tests were compression-molded into panels in a hydraulic press (Erie Mill Co. Erie, PA.) at 190°C for 5 minutes under 6.2 MPa pressure to reduce their thickness to 2.8 mm. The notched Izod impact strength of the samples was determined using a Tinius Olsen Izod impact tester at room temperature according to the procedure outlined in ASTM D256 (ASTM, 2003). The statistical average of the measurements of at least 15 specimens was taken to obtain reliable average and standard deviation. For selected samples, water absorption and thickness swelling tests were also performed.

3. RESULTS and DISCUSSION

3.1. Physical and Mechanical Properties of PBs

The results of mechanical and physical properties test of PBs were summarized in Table 1 and 2. Table 1 shows mechanical and physical properties of aspen and ash PBs at 650 Kg/m^{3}of target density but at the different resin content

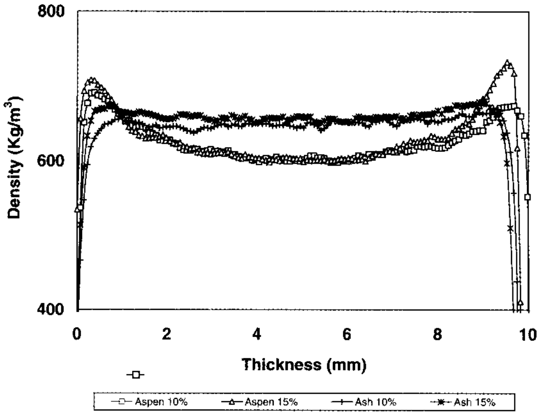

Fig. 1. Average density profile of aspen and ash particleboards.

(10 and 15%). As expected, increase in resin content improved MOR, MOE, and IB in both aspen and ash PBs. Literatures also indicated that as the resin contents of PBs increased, mechanical properties also increased (Hann *et al.*, 1963; Kimoto *et al.*, 1964; Lehmann, 1970). The increase in MOR and MOE due to the increase of resin content was 54.6% for aspen and 26.8% for ash boards in MOR and 50.2% for aspen and 22.5% for ash boards in MOE.

In general, MOR and MOE values of aspen boards are much greater than those of ash boards at the same resin content. MOR of aspen at 10% resin content were about 96% higher than that of ash and at 15% resin content, the difference were increased to 138%. Low MOR and MOE values for ash board may be due to insufficient compaction of ash particles since the compaction ratio (density of PB/density of wood used) of the ash board was 1.06 ~ 1.08 while that of aspen was 1.65 ~ 1.69, provided that the density of ash wood is around 600 Kg/m^3 while that of aspen wood is 380 Kg/m^3 (Miller, 1999). It was also suspected that compaction ratio could influence internal structure known as density profile, which greatly affects bending properties of PBs. Therefore, density profile of the aspen and ash boards were measured using X-ray density profiler (Fig. 1). From the Fig. 1, it was clear that at a given density of the board (about 650 Kg/m^3), the aspen boards that had high surface density and low core density, which is known as conventional "M" shape density profile in PB. However, ash board had more uniform density through the thickness. Since the density at the surface layer suffers higher stress during bending test, boards with higher surface density perform better than the boards with uniform density profile. For aspen and ash boards with 650 Kg/m^3 of density, there was no big difference in density profile between 10 and 15% resin content.

Ash PB with increased compaction ratio was thus made to find out the effect of compaction ratio on bending properties. The target density was increased from 650 Kg/m^3 to 787 Kg/m^3 and 930 Kg/m^3 so that the compaction ratio increased from 1.06 to 1.32 and 1.55. All other manufacturing parameters were kept identical. As expected, the MOR and MOE values significantly increased as board density increase (Table 2). This finding is well agreed with literatures which indicated that the density of the PB need to be higher than that of wood furnish to get sufficient inter-particle contact (Hse, 1975; Larmore, 1959; Vital *et al.*, 1974). Clearly, compaction ratio is directly proportional to the PB density at a constant furnish wood density. Therefore bending properties of the PB that directly affected by board density was increased as compaction ratio increased.

As we found in the density profile of ash and aspen boards, we assumed that the increased bending properties at high compaction ratio in ash boards are also due to the difference in density profile. Density profile is a consequence of complicate mechanisms, which interaction among heat and moisture transfer, adhesion and rheology creates spatial density distribution through the thickness direction during hot pressing process of PB manufacturing (Humphrey, 1994). Thus density profile through the thickness of the PB at low compaction ratio may be different from the one at high compaction ratio provided that all processing parameters are identical. The density profile of the ash boards at 3 different compaction ratios was examined with X-ray densitometer and shown in Fig. 2.

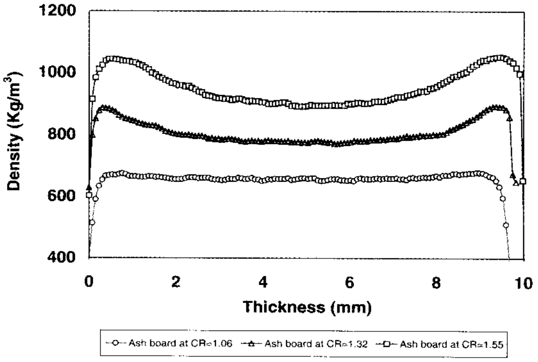

Fig. 2. Average density profile of ash boards at three different compaction ratios.

The density profile of ash board indicated that when the compaction ratio of ash board was increased to 1.06 to 1.32 or 1.55, the density profile changed from flat to M shape. As expected, the bending properties of the ash board significantly increased as compaction ratio of the board increased. The density profile results suggested that the increase in ash board density increased compaction ratio of the board and also led to change in density profile and thus positively affect bending properties of the board.

In general, IB strength values of aspen were lower than those of ash. This result may be due to the low density at mid-thickness area compared to the ash boards. Increasing compaction ratio (or board density) in ash board also increased IB strength. This also may be due to the increased density at the core region. The IB strength of both aspen and ash board increased 63% and 57% respectively as resin content raised from 10% to

Table 1. Mechanical and physical properties of the particleboards made with aspen and ash

Board Density (Kg/m^3)	Resin content (%)	Compaction ratio[a]	MOR (MPa)[b]	MOE (MPa)[b]	IB (MPa)[b]	Thickness swelling (%)[b]	Water absorpion (%)[b]
Aspen Boards							
627	10	1.65	10.5 (1.0)	1789 (274)	0.26 (0.1)	24.3 (2.1)	115.3 (4.1)
641	15	1.69	16.1 (1.4)	2687 (120)	0.43 (0.1)	25.3 (1.6)	104.4 (6.6)
Ash Boards							
650	10	1.08	5.3 (1.2)	836 (228)	0.44 (0.1)	16.4 (1.2)	96.6 (4.3)
635	15	1.06	6.8 (1.1)	1025 (121)	0.70 (0.1)	14.2 (1.4)	86.3 (4.8)
ANSI Standard							
640-800			11~16.5	1725~2750	0.4~0.6		

[a] Compaction ratio was calculated based on the ratio of board density to furnish wood density. aspen wood density= 380 Kg/m^3 ash wood density=600 Kg/m^3

[b] Numbers in the parenthesis are standard deviation.

Number of replicates: MOR and MOE = 9, IB = 15, thickness swelling and water absorption = 9

Table 2. Mechanical and physical properties of the ash particleboards at three different compaction ratios

Board Density (Kg/m^3)	Resin content (%)	Compaction ratio[a]	MOR (MPa)[b]	MOE (MPa)[b]	IB (MPa)[b]	Thickness swelling (%)[b]	Water absorpion (%)[b]	Screw holding	
								Face (N)[b]	Edge (N)[b]
Ash Boards									
635	15	1.06	6.8 (1.1)	1025(121)	0.70(0.1)	14.2(1.4)	86.3(4.8)	1065(119)	834(42)
794	15	1.32	13.6 (1.0)	1988.3(133)	1.12(0.1)	20.9(0.5)	75.7(2.3)	2481(90)	1978(133)
930	15	1.55	24.0 (2.3)	3451.3(299)	1.74(0.1)	24.3(1.1)	69.6(2.7)	3433(148)	2932(99)
ANSI Standard									
640~800			11~16.5	1725~2750	0.4~0.6			900~1100	800~1000
>800			16.5~23.5	2400~2750	0.9~1.0			1800~2000	1325~1550

[a] Compaction ratio was calculated based on the ratio of board density to furnish wood density. ash wood density=600 Kg/m^3

[b] Numbers in the parenthesis are standard deviation.

Number of replicates: MOR and MOE = 9, IB = 15, thickness swelling and water absorption = 9 and screw holding Face = 6, Edge = 4

15%.

Thickness swelling and 24 hr water absorption of ash board decreased as resin content increased. It is interesting to note that the thickness swelling of ash board increased as resin content increase. This could be due to the slightly higher density of the 15% ash board compared to 10% one. For aspen board, thickness swelling slightly increased while water absorption decreased with increasing resin content. Thickness swelling of aspen board is generally higher than that of ash board. This may be attributable to the spring back of highly compacted aspen particles during hot pressing. When immersed in water, highly compressed aspen particles tend to swell more than less compacted ash particles. As compaction ratio of ash boards increased, water absorption decreased but thickness swelling increased. The decreased water absorption of high compaction ratio board may be due to the decreased porosity and increased amount of wood material in the board. However the increase in the thickness swelling may be due to the spring back of more compressed wood particles at high compaction ratio. This finding is agreed with the results from Roffael and Rauch (1972) who reported that the increase of the board density decreased water absorption but increased thickness swelling. Screw withholding properties (both face and edge) of ash PB were higher than the requirements for PB, independent of panel density.

3.2. Physical and Mechanical Properties of WPCs

The mechanical and physical properties of the ash/HDPE and ash/PP with additives are shown in Table 3. The MOR of the ash/HDPE composite without coupling agent was lower than those with coupling agent (G2608) as anticipated. This is because of the improved compatibility and bonding between polar wood and non-polar thermoplastic (Chun and Woodhams, 1984; Woodhams *et al.*, 1984). However, MOE of ash/HDPE composites tended to slightly decrease as coupling agent added. Ash was also processed with PP with or without coupling agents. Again, MOR value of the ash/PP without coupling agent was lower than those with coupling agents. The increase of MOR values was 17% with G3003 and 12% with E-43. It was clear that MOR values of WPCs made with PP is higher than those made with HDPE which may be attributable to higher bending strength of PP than HDPE.

Table 4 shows the effect of wood species on the physical and mechanical properties of WPC.

Table 3. Effect of matrices and additives on mechanical and physical properties of wood plastic composites

Samples	Weight ratio	Temperature profile (°C, hopper to die)	Screw speed (rpm)	MOR (MPa)[a]	MOE (MPa)[a]
Ash:HDPE					
Ash:HDPE:TPW104	50:44:6	190-175-150-150	20	27.6 (0.8)	1671 (30)
Ash:HDPE:TPW113:G2608	50:41:6:3	190-170-140-140	30	40.6 (1.3)	1422 (32)
Ash:PP					
Ash:PP:TPW104	50:44:6	190-165-160-155	40	36.4 (1.2)	2358 (84)
Ash:PP:TPW113:E-43	50:41:6:3	190-175-170-165	40	38.1 (1.4)	2637 (107)
Ash:PP:TPW113:G3003	50:41:6:3	190-165-160-155	20	39.9 (2.7)	2268 (203)

[a] Numbers in the parenthesis are standard deviation.
Numbers of replicates: 15

Table 4. Effect of wood species on physical and mechanical properties of wood plastic composites

Wood Species in WPCs	MOR (MPa)[a]	MOE (MPa)[a]	Impact resistance (N/m)[a]	Thickness swelling (%)[a]	Water absorption (%)[a]
Wood:HDPE composites					
Ash flour	27.6 (0.5)	1674 (26)	24.0 (3.1)	1.71 (0.21)	1.97 (0.07)
Pine flour[b]	25.3 (0.8)	2049 (133)	27.1 (2.7)	0.83 (0.19)	1.83 (0.03)
Maple flour[b]	27.1 (0.6)	2122 (82)	27.8 (1.9)	1.28 (0.25)	2.12 (0.05)
Wood:PP composites					
Ash flour	36.4 (1.2)	2356 (84)	16.3 (1.1)	1.47 (0.10)	1.80 (0.11)
Pine flour[b]	27.8 (4.7)	2366 (369)	23.2 (3.2)	1.09 (0.16)	0.91 (0.03)
Maple flour[b]	34.4 (2.5)	2510 (246)	23.5 (2.0)	1.10 (0.11)	1.05 (0.04)

[a] Numbers in the parenthesis are standard deviation.
[b] Data from Maurice and Matuana (2004)
Numbers of replicates: MOR and MOE = 10, Impact resistance = 15, and thickness swelling and water absorption = 10

Overall, bending strength (MOR) and stiffness (MOE) values of ash/HDPE and ash/PP composites compared favorably to those made with pine and maple. It should be mentioned that the MOE of ash/HDPE composites was slightly lower compared to pine and maple counterparts. Regardless of the plastic matrix type, the notched Izod impact strengths of ash-based WPCs were lower compared to those of pine and maple counterparts. Wide range in particle size and/or the presence of bark in ash furnish used in WPC manufacture may explain this difference. Generally, wood plastic composites made with polypropylene matrix outperformed their polyethylene counterparts in strength and stiffness, regardless of wood species, due primarily to the higher stiffness of polypropylene. We observed an opposite trend in Izod impact strength, where softer polyethylene-based WPCs had stronger impact resistance than their polypropylene counterparts. Thickness swelling and water absorption of ash/HDPE and ash/PP are generally higher than other species. This could be due to the various particle size and/or presence of bark in ash furnish.

4. CONCLUSIONS

The preliminary results indicated that value-added wood products such as PB and WPC could be successfully produced from the ash trees removed by EAB eradication program. For PB manufacturing, aspen was also used as comparison. In general, mechanical properties such as bending properties of aspen boards were superior to those of ash boards at a given board density. This could be attributable to high compaction ratio and high surface density of aspen board. However, IB of ash board was higher than that of aspen board, which may be due to the high density at the mid-thickness region. In addition, ash boards had lower thickness swelling and water absorption compared to aspen boards. The increase of UF resin content from 10 to 15% did improved physical and mechanical properties of both aspen and ash boards.

In order to find out the effect of compaction ratio on board properties, ash boards with different densities were manufactured. As the compaction ratio of the ash board increased from 1.06 to 1.32 and 1.55, mechanical properties were greatly increased. Moreover, density profile study indicated that ash board at low compaction ratio result in flat density profile while high compaction ratio produced conventional "M" shape density profile, which may affected bending properties. IB and screw holding properties also increased as board density increased. However, as board density increased, thickness swelling was increased while water absorption was decreased. Aspen board absorbed more water than ash at all resin content. For both boards, water uptake was reduced as resin content increased.

WPCs were manufactured with ash flours, thermoplastics (HDPE or PP) and additives. The bending properties of the ash/HDPE or ash/PP composites were improved when coupling agents were used. Overall, the bending properties, impact resistance, water absorption and thickness swelling properties of the WPCs made with ash compared favorably to those made with pine and maple regardless of the polymer matrix type.

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