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Effect of Wood-Fiber Characteristics on Medium Density Fiberboard (MDF) Performance*[1]

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ABSTRACT

Four different sources of wood-fibers from Eucalyptus, Italian poplar, hemlock, and mixed species fibers were used to study the influence of their fiber characteristics on the performance of medium density fiberboard (MDF) panels bonded with both urea-formaldehyde (UF) and phenol-formaldehyde (PF) adhesives. Included fiber characteristics were fiber length, size distribution, bulk density, and acidity. Physical and mechanical properties of MDF panels manufactured by dry process using these different fibers were determined for the comparison of board performance. Two hardwood species had a large fraction of short fibers resulting in a higher bulk density while very long hemlock fibers had lower bulk density. Fiber acidity was revealed to strongly affect the internal bond (IB) strength of MDF panels bonded with UF resins. MDF panels made from mixed species fibers showed highest IB strength of all panels prepared. UF-bonded MDF panels showed poor dimensional stability. In conclusion, the present study showed that wood-fiber characteristics such as fiber length, bulk density, and acidity affect the performance of MDF boards. and also suggested that fiber characteristics be considered for MDF panel manufacture.

Keywords : Fiber characteristics, fiber length, bulk density, UF resin, PF resin, MDF performance

1. INTRODUCTION

Fiberboard is manufactured by reconstituting fibers as raw materials into a panel, and can be classified by its density. Insulation board represents the lowest density range of 160~480 kg/m^3, and is manufactured by wet process like paper. Medium density fiberboard (MDF) is made by either wet or dry process in a density range of 640~800 kg/m^3. High-density fiberboard called hardboard has a density range of 881~1121 kg/m^3. MDF is a relatively new type of wood-based composite materials compared to traditional particleboard.

The total MDF panel production in South Korea reached 912 thousands m^3 in 2000. It is expected to increase to 1 million m^3 in 2001 as the production of MDF panel is growing in worldwide (Park, 1999). The global scarcity and the high cost of quality timber, and utilization of low cost mill residues are boosting an increase in MDF production. In addition, MDF panels have good mechanical and physical properties as well as some features; good

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machinability comparable to solid wood, relative insensitivity with the quality of raw material, molding ability for wide variety of surface decorations, smooth surface suitable for various finishing, and tightness of edge (Chapman 1998).

MDF can be made from almost any lignocellulosic raw materials. However, wood-fiber is the main raw material because of its relative abundance and year-around availability. A change or substitution of a raw material for another requires process modification or entirely new approaches to manufacturing process. Quite a lot of researches have been done on the relationship of anatomical and chemical properties of wood-fibers with the nature and properties of paper by many paper technologists. Dinwoodie (1965) has done one excellent review on the effect of wood fiber characteristics on paper properties, and identified three significant characteristics of wood-fibers, that is, fiber density, fiber length and strength in descending order of importance in terms of paper properties. It is expected that these properties will affect, at least generally, the performance of MDF panels. However, it is not clear how these properties influence the properties of MDF panels.

Nelson (1973) did an extensive work on the effects of wood and pulp properties on dry-formed medium density hardboard. He investigated specific gravity and fiber length as wood properties, and fiber length index, lignin content, pH, and fiber mat bulk density as pulp properties. Comparing the properties of hardboard bonded with alkaline phenolic resin, he reported negative relationships between most of strength properties and wood specific gravity, and bulk density of fiber mat. In addition, the author found a positive relationship of all strength properties and linear stability with pulp pH.

It is well known that particle geometry affects particleboard properties in a wide variety of ways, and interacts with many other important factors in board manufacturing (Maloney 1993). For example, the quality of furnish particle is controlled by wood species properties such as density, acidity, extractive content, and machinability (Kelly 1977). It is known that the acidity of wood furnish affects the curing rate of UF resins when it was used as a binder for wood-based composites (Albritton and Short 1979; Slay *et al.* 1980; Myers 1977; Johns and Niazi 1980; Albert *et al.* 1999). A definite relationship between extractive content and the gluability of wood was also reported by other studies (Bryant 1968; Chen and Paulitsch 1974; Jain *et al.* 1975).

Fiber acidity varies between wood species as well as within species (McNamara *et al.* 1970; Albritton and Short 1979; Albert *et al.* 1999). McNamara *et al.* (1970) found differences in pH between sapwood and heartwood of northeastern wood species but a small effect of the tree-cutting season on the pH. Subramanian *et al.* (1983) described a new method of determining the acidity of wood by water extraction and titration. They reported that bound acids concentration was correlated better with gel time of UF resin than soluble or total acid.

By determining hexane-, ethanol-, and water-soluble extractives, Chen and Paulitsch (1974) attributed the difficulties in gluing to the amount of fatty substances, waxes and oil, and the improvement in subsequent formaldehyde liberation to the high amount of tannic acid and phlobaphenes in pine and spruce. Albritton and Short (1979) reported that two major extractives of both ethanol- and water-soluble components had a significant effect on UF resin gel time. The ethanol-soluble extractives decreased the gel time as much as 41 percent, while the water-soluble extractives increased the gel time up to 65 percent. Slay *et al.* (1980) reported that the gel time of UF resin increased exponentially as the pH of the resin-extractive mixtures increased. Although most of studies were concerned with wood acidity of species for UF resins, Myers (1977) investigated the effect of fiber acidity on the performance of dry-formed hardboard bonded with both novolac and resole PF resins. He found that optimum acidity level was dependent on PF resin type, and the variation of hardboard properties could be minimized by controlling fiber acidity. More recently, Johns and Niazi (1980) have studied the pH and buffering effect of several species of wood on the gel time of UF resin. They found a strong correlation between the gel time and pH or acid buffering capacity of water extract. Setera (1990) reported that the acidity and buffering characteristics of different wood species are most concerned aspects for manufacturing of interior particleboard bonded with urea-formaldehyde (UF) resin which cure under acidic conditions.

Compared with abundant research results on the effect of fiber acidity, a limited result is available for the influences of fiber size distribution, acidity, and bulk density on MDF properties. Therefore, this study was performed to investigate the influence of wood-fiber characteristics to MDF panel performance.

2. MATERIAL and METHOD

2.1. Materials

Four different wood-fiber sources were used in this study: Italian poplar (*Poplus canadensis* Moench), Eastern hemlock (*Tsuga canadensis*), eucalyptus, and mixed species. A specific wood species was not identified for Eucalyptus fibers, which are of a very reddish. The mixed species fibers consisted of 75% of softwood species (mainly black spruce and fir) and 25% hardwood species (mainly birch) from a local MDF mill.

2.2. Experimental methods

A light microscope was used to measure the fiber length of each species of wood-fiber with 50 replications using a micrometer. To obtain fiber size distribution of these wood-fibers, dry sieving was also done using a Ro-Tap Shaker. The sieve aperture sizes used were from 3350 to 177 m, corresponding to Tyler mesh number from 6 to 80. Sieve data were obtained by weighing the appropriate sieve trays before and after sieving 30 g samples for each test. Each sieving time was about 15 minutes. Bulk densities of uncompressed wood-fibers were measured by pouring wood-fibers into 1L glass beaker and weighing the weight. Acidity of wood-fibers was measured using a pH meter according to a modified TAPPI standard method (TAPPI, 1989). Wood-fibers (20 g) were dispersed in distilled water (100 cc) and mixing for twenty-four hours, and then this solution was used for the pH measurements.

The fibers were dried to about 3% moisture content, and then blended with either UF or PF resins in a rotary drum blender. The resins were applied at 8% solids based on oven dry weight of the furnish fibers. Before the resin application, 1% based on oven dry weight of the fiber of either emulsified wax for UF resin or slack wax for PF resin was applied onto the furnish fibers in the same blender. A pumping system in conjunction with a pressurized atomizing air stream was used to deliver and atomize wax and resin. The dried fibers were felted into a mat of 50.8 cm by 61 cm with a target density of 750 kg/m^3 using a fiber-felting machine. Two fiber mats were prepared and prepressed. Then these two mats were put together and hot pressed at 180℃ for UF resin and 205℃ for PF resin for 7 minutes. The initial pressure was allowed to increase to 4.5 MPa. After approximately 15 seconds, the pressure was reduced to 3.8 MPa and maintained for 3.75 minutes. The pressure was further decreased to 2.3 MPa and maintained for 2.5 minutes. The pressure was completely released over the last 30 seconds.

According to the method of ANSI standard (1994), the mechanical properties of prepared MDF panels included dry static bending modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) strength. One MDF panel was prepared for each type of wood-fibers and resins. From the prepared boards, nine specimens were cut for IB strength tests and three specimens for dry MOR and MOE.

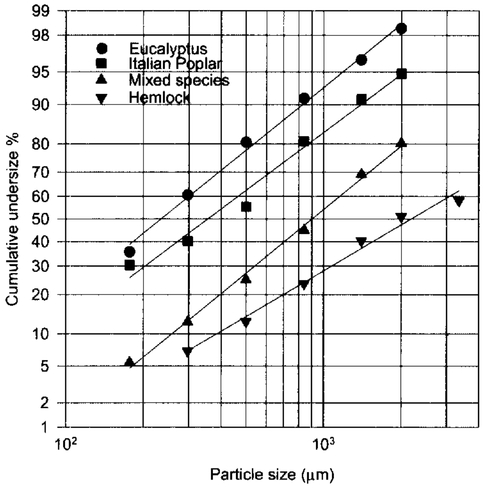

Fig. 1. Fiber size distribution obtained by dry sieving method.

3. RESULTS and DISCUSSION

Fiber length measured with light microscopy varied with wood species. Eucalyptus fibers had a large portion of short fibers (less than 1 mm) with an average fiber length of 0.52 mm. Italian poplar fibers also had a similar range of fiber length with an average fiber length of 1.1 mm. Hemlock fibers occasionally had a bunch of large fiber bundles that are longer than 7 mm in length, and the average fiber length was 1.9 mm. The mixed species showed the presence of both short and long fibers with an average of 1.5 mm. This result shows a general trend that hardwood fibers have larger portion of relatively short fibers than softwood fibers do. This may be explained anatomical difference between hardwood and softwood. In other words, hardwood species generally have short fibers such as vessel element, parenchyma, libriform fiber, and ray cells, while softwood fibers are mainly consisted of relatively long tracheids.

To compare wood-fiber length distributions of the species, dry sieving was also done with various aperture sizes of mesh. The result was shown in Figure 1. As expected, the fiber length distribution was quite similar to the fiber length measurement by light microscopy. Hardwood fibers such as eucalyptus and Italian poplar showed large portion of very short fibers. For example, two hardwood (eucalyptus and Italian poplar) species had 93% and 83% of fibers that were less than 1 mm in length, respectively. The fiber length distribution of mixed species is intermediate between hardwood and softwood fibers, or hemlock fibers.

Bulk densities of four different wood-fibers are shown in Figure 2. As expected from the fiber length distributions, the bulk density was dependent on wood species. The hemlock fibers that had a broader fiber length distribution showed the lowest bulk density among four different fiber types. This might be attributed to the presence of long fibers that give more open structure than short fibers (Suchsland and Woodson 1991). However, two hardwood fibers showed much greater bulk density than that of softwood fiber. This is possibly due to the short fibers, leading to denser structures between fibers. But the mixed species show the largest

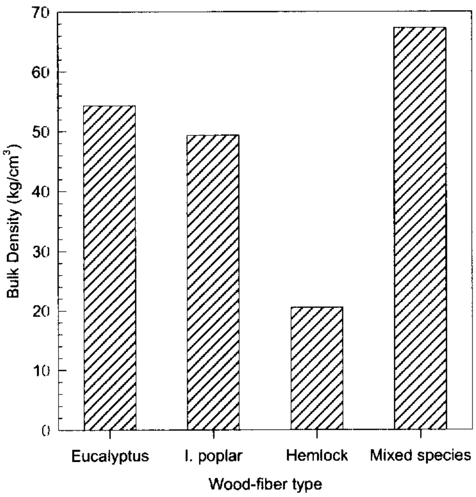

Fig. 2. Fiber bulk density of wood-fiber from four different sources.

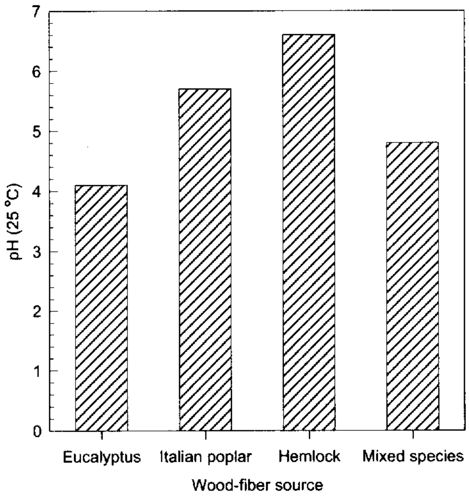

Fig. 3. Fiber pH of wood-fiber from four different sources.

bulk density among these different fibers. This might be due to a proper compaction of short fibers into the spaces between long fibers. Bulk density of wood-fibers highly affects fiberboard performance. In general, lower bulk density fibers result in higher compaction ratio, subsequently producing stronger fiberboard than that from higher bulk density fibers (Suchsland and Woodson 1991).

Figure 3 shows the result of pH measurements of the fibers (or the fiber acidity). Eucalyptus fibers showed the lowest acidity of about 4.1, followed by mixed species, Italian poplar, and hemlock fiber in ascending order. As shown, the fiber acidity varied depending on wood species. One possible reason might be the extractives which are, in many wood species, highly acidic. In fact, eucalyptus fibers were of a very reddish color indicative of large quantities of extractives. Gutierres *et al.* (1998) reported that *Eucalyptus globuslus* had relatively high extractives composed of sterols, sterol esters, fatty acids and ketones. The pH of fibers was known important for wood-based composites bonded with UF resin curing in the acidic conditions (Kennedy 1990).

Determined mechanical and physical properties of MDF panels bonded with both UF and PF resins were internal bond (IB) strength, modulus of rupture (MOR), modulus of elasticity (MOE), thickness swelling and water absorption. One of the weakest points of wood-based composite materials produced by hot-pressing process is located in the midpoint of the board thickness, which is the lowest density region. The IB strength or tensile strength perpendicular to the board surface is an important and widely determined property. Figure 4 shows the IB strengths of MDF panels from four different fiber types. The lowest IB strength was found in the MDF panel made from hemlock fibers. PF-bonded MDF panels made from two hardwood fibers had similar IB strengths while UF-bonded MDF panels made from Italian poplar fibers showed lower IB strength than that from eucalyptus fibers. Regardless of resin types used, the best IB strength was found in the MDF panel made from the mixed species fibers.

These results might be related to many

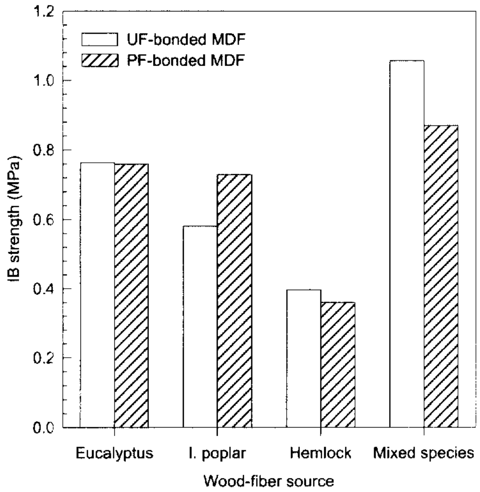

Fig. 4. Internal bond (IB) strength of MDF panels made from four different sources.

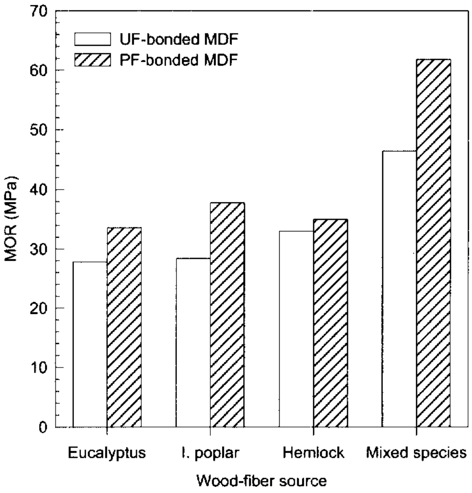

Fig. 5. MOR of MDF panels made from four different sources.

factors including the adhesive bond strength, fiber surface area, internal mat structure, fiber acidity, and hot-pressing conditions. The lowest IB strength that occurred in MDF panels made from hemlock fiber might be resulted from either fiber pH, or internal mat structure. As shown in Figure 3, the hemlock fibers were very alkaline with a pH of 6.6. This high alkalinity of the fiber retards the curing of UF resin which cures in acidic condition. Another possibility could be its lower bulk density, which makes it difficult to form a mat during MDF preparation (Figure 2). These explanations can be supported by the result of eucalyptus fibers. The MDF panels made from eucalyptus fiber showed much better IB strength than that from hemlock fibers. Lower pH of eucalyptus fiber (pH: 4.1) may improve the curing of UF resin during hot-pressing process. However, a combination of both relatively lower pH (4.8) and proper internal mat structure might be the probable explanation for the highest IB strength of MDF panels from mixed species fibers. In addition, the relatively large amount of short fibers in hardwood species may also consume more adhesives due to larger fiber surface area than long softwood fibers. This might be an explanation for lower IB strength of MDF from hardwood fibers than that from mixed species fibers.

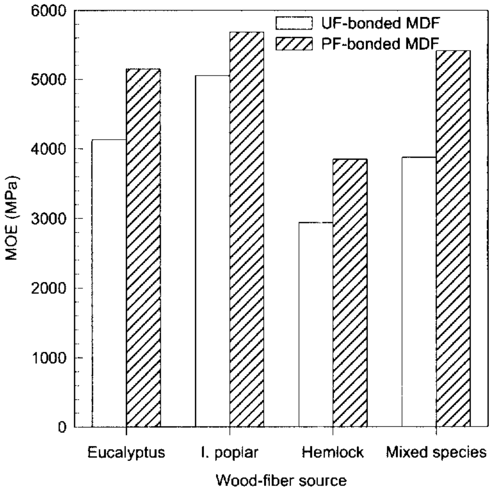

Fig. 6. MOE of MDF panels made from four different sources.

Both MOR and MOE were shown in Figures 5 and 6. In general, all PF-bonded MDF panels showed better MOE than UF-bonded MDF panels. But, the MDF panels bonded with PF resins generally gave darker color than those bonded with UF resins. This might be attributed to inherently reddish color of PF resins. And MDF panels from the mixed species showed highest MOR values. However, the MOE value is highest for MDF panels from Italian poplar fibers.

Since MOE is highly dependent on the quality of panel surface, this result might be resulted from greater stiffness of cured PF resin than the counterpart of UF resin. Another possible explanation may be either the presence of bunch of long fiber bundles or relatively long fiber length, resulting in the increased chance of defects in MDF panel surfaces. Long fibers will produce more open structures, which may play as a crack initiation point. The lowest MOE value was found for softwood hemlock fiber among four different fiber species regardless of adhesive types used. MDF panels made from two hardwood fiber species showed similar results, but those panels made from the mixed wood specie fibers were in between. All MOE values satisfied the ANSI requirement level of 2400 MPa (ANSI A208.2 1994).

In general, MOR values of MDF panels prepared from both two hardwood-fibers (eucalyptus and Italian poplar) and softwood fiber (hemlock) were similar with each other. However, MOR of MDF panels made from mixed species fibers showed highest values regardless of adhesive types used. This might be attributed to internal mat structure of MDF panel. In other words, mixed species fibers were thought to have a proper internal mat structure. Shorter fibers from hardwood species may reduce open spaces made by long softwood fibers during mat forming process. Thus, proper compaction of fibers by combining short and long fibers could reduce a chance of possible defects in internal mat of fiberboard. But, it is not clear in this study what an optimum combination ratio of short and long fibers, or hardwood and softwood fibers is.

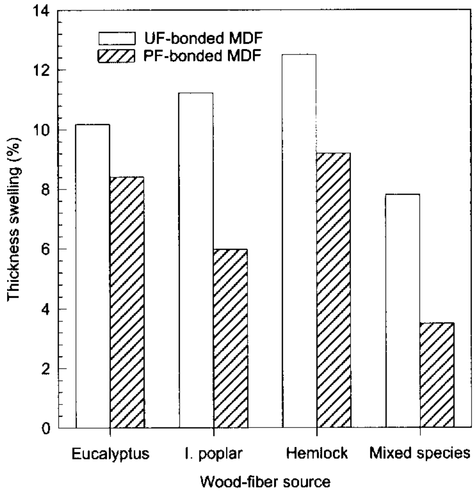

Fig. 7. Thickness swelling of MDF panels made from four different sources.

Figure 7 shows the results of thickness swelling measured at 1 inch (2.54 mm) position from the board edge after soaking in cold water for 24 hours. As expected, UF-bonded MDF panels showed greater thickness swelling than PF-bonded MDF panels. In addition, MDF made with hemlock fibers have the greatest thickness swelling among all wood-fiber types regardless of adhesive types. It was also observed that thickness swelling was inversely related to the IB strength of MDF panels. In other words, the greater the IB strength of MDF panels, the less the thickness swelling of the panel.

Figure 8 shows water absorption of MDF panels after soaking in cold water for 24 hours, and the water absorption followed a similar trend as the thickness swelling. In general, UF-bonded MDF panels showed much larger water absorption than PF-bonded MDF panels. This might be partially due to the reversibility of methylolation reaction between urea and formaldehyde. This reversibility of was reported

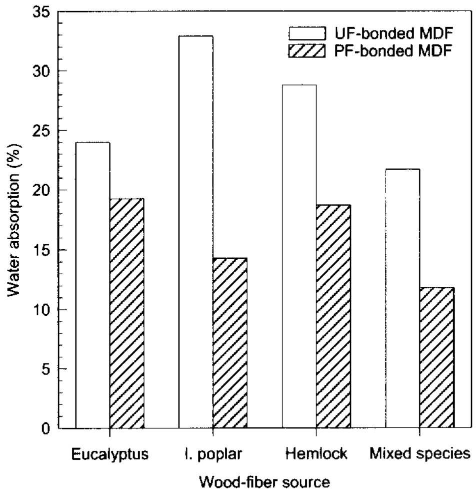

Fig. 8. Water absorption of MDF panels made from four different sources.

Table 1. The constant parameters for manufacturing MDF panels.

Parameters	Condition
Board size	19.1 mm×508 mm×609.6 mm (3/4 in.×20 in×24 in)
Target board density	750 kg/m^3
Wax content	1% (relative oven dry fiber weight by solids basis)
Fiber moisture content	3%
Resin content	8% of oven dry fiber weight by solids basis
Resin type	commercial UF, or PF resole resins
Platen position (%)	111
Creep closing time (min.)	4.0
Hot pressing temperature	180℃ for UF resin and 205℃ for PF resin
Total hot pressing time	7 minutes

to be responsible for both lower resistance against hydrolysis caused by the attack of moisture or water and the subsequent formaldehyde emission (Dunky 1998).

4. CONCLUSIONS

Both eucalyptus and Italian poplar fibers had a large fraction of short wood-fibers while hemlock fibers had long fibers as well as large fiber bundles. Short hardwood fibers produced greater bulk density than long softwood fibers did. The fiber length and its distribution were related with fiber bulk density, affecting the construction of internal mat structure of MDF. MDF panels from mixed species fibers showed the highest in the IB strength of all panels prepared. IB strengths of MDF panels were strongly dependent on both the fiber acidity (pH) affecting the curing rate of UF resin and the internal mat structures that resulted from fiber length and its distribution. Both the MOE and MOR were better in PF-bonded MDF panels than in UF-bonded MDF panels. The PF-bonded MDF panels showed better dimensional stability than the UF-bonded MDF panels. In conclusion, the present study suggested that wood-fiber characteristic such as fiber length, and distribution, and fiber bulk density as well as chemical properties such as fiber acidity (pH) had an influence on the performance of MDF boards.

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