ASSESSING THE EFFECT OF SWELLING PRESSURES IN PARTICLEBOARD AND MDF USING ACOUSTIC EMISSION TECHNOLOGY

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ABSTRACT

The interaction of moisture with wood-based composites leads to the development of swelling pressures that cause the failure of resin bonds and the dislocation of fibers within the composites. These bond failures and dislocations can result in abrupt stress changes that trigger vibrations and create acoustic emissions (AE). Resin and wax levels within the composites effectively limit the interaction of wood and water and affect the level of AE. In this research, acoustic emissions were used to measure the effects of resin and wax levels in both particleboard and medium density fiberboard (MDF).

Two resin levels and three wax levels in the composites were tested. Samples were immersed in distilled water for 120 min during which cumulative AE were recorded. In addition, the density and moisture content gains of the samples were determined.

The results provide evidence that both resin and wax levels significantly affect the number of acoustic emissions and the failure of internal bonds within the samples. Increasing the percentage of wax reduced the level of acoustic emissions in both the MDF and particleboard. Increasing the percentage of resin significantly affected the levels of AE in both MDF and particleboard, although in different ways because of the differences in internal structure within the composites. Acoustic emission technology could be a useful tool in assessing the quality and consistency of the composites.

Keywords: Acoustic emissions, nondestructive testing, wax, particleboard, resin, medium density fiberboard.

INTRODUCTION

Wood-based composites are an increasingly important segment of the forest products industry. Because of their hygroscopic nature, they absorb both liquid water and water vapor. The change of moisture content can severely affect dimensional stability and limit utilization. The work described in this report examined the interaction of medium density fiberboard (MDF) and particleboard with water using acoustic emission technology. The purpose of the research was to determine whether using acoustic emission technology could be a viable and reliable method of examining two quality-related attributes of MDF and particleboard. The specific objectives of the research were to determine if a relationship exists between cumulative acoustic emissions (AE counts) and resin levels in both MDF and particleboard during swelling and to determine if a relationship exists between cumulative AE counts and wax levels in both MDF and particleboard undergoing swelling.

Liquid water has little potential to swell ei-

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ther solid wood or composites made from wood. Because of its hygroscopic nature, wood interacts with water vapor, and the interaction consequently results in swelling pressures within and between the cell walls and in areas where microvoids exist. Tarkow and Turner (1958) used the following equation to calculate swelling pressure within wood that is exposed to water vapor:

$$P_c = \frac{RT}{\bar{V}} \ln \frac{P_o}{fP_i} \qquad (1)$$

Where:

- f: an activity factor (usually 1 for water vapor)
- P_c: maximum swelling pressure (atm)
- P_i: initial water vapor pressure in wood substance (atm)
- P_o: saturated (final) vapor pressure in wood substance (atm)
- R: gas constant (82 atm cm^3)/(mol K)
- T: absolute temperature (K)
- $\bar{V}$: molar volume of absorbed water (cm^3)

Over time, either within solid wood or wood-based composites, swelling pressures develop and cause the dislocation or microfracturing of the stressed tissues or the adhesive bonds that hold the composite intact. The dislocation and microfracturing lead to abrupt stress changes that are a source of acoustic emissions. The emissions can then be monitored by using sensitive equipment. Because of the interrelationship between swelling pressure, tissue dislocation, microfracturing, and acoustic emissions, it was hypothesized that acoustic emissions might be used as a measure of the interaction of the composites with moisture. If true, the method might prove an effective technique for assessing the effects of process changes and for monitoring process consistency.

To accomplish the objectives and establish the functionality of the approach, two key parameters that are known to be affected by moisture content were varied. The first was resin level, which affects dimensional stability, density, moisture resistance, and internal bond (IB) strength (Haygreen and Gertjejansen 1972; Generalla et al. 1989; Schneider et al. 1996). The second parameter was the wax level within the composites. Wax is sprayed on the fibers and particles of wood-based composites to improve water repellency. The application of wax significantly influences both water adsorption and dimensional stability (Winistorfer et al. 1996).

BACKGROUND

When solid wood or wood-based composites are exposed to liquid water, moisture gain can occur, primarily, by two mechanisms. The first is liquid water transport, which is generally modeled directly or indirectly using Darcy's law. The second mechanism, found where the void spaces are small, is diffusion. Diffusion is generally modeled using Fick's laws and by considering vapor pressure, chemical potential, or a similar driving force as the prime mover (Skaar 1988).

Hygroscopic materials, such as wood, swell because of the action of water molecules or vapor. As water vapor diffuses into the cell walls and microvoids, swelling pressures are generated that move tissues. Tarkow and Turner (1958) applied Eq. (1) to quantify the effect. Conversely, liquid water, found in pores and larger interstitial spaces within composites, causes no swelling pressures to develop. Swelling pressures derived from vapor can be very large, and using Eq. (1), the authors calculated that swelling pressures at room temperature exceeded 158 MPa when wood equilibrated at 30% relative humidity was exposed to saturated environments. They also reported that the swelling pressures in wood increased rapidly with the extent of densification of the wood. It was concluded that the swelling pressures not only caused wood to deform, but also caused microfractures within the fibers.

Within a wood-based composite, such as particleboard, the resin level has a significant influence on dimensional stability. Schneider et al. (1996) found that increasing the resin content significantly increased IB strength and decreased both the magnitude of thickness swelling and the amount of water adsorption. Suchsland (1973) found that the hygroscopic thickness swelling and moisture absorption were proportional in ten commercial particleboards.

The adsorption of moisture by medium density fiberboard also has a pronounced effect on its properties. Bennet (1969) measured swelling as the relative humidity was increased from 30 to 90% and found that swelling along the length of the board was 0.19–0.28% and the thickness swelling was 4.3–15%. Stillinger and Coggan (1956) and Brown et al. (1966) found that the strength of MDF decreased significantly with moisture increases, indicating that internal bonds were being fractured.

During the manufacturing of both particleboard and MDF, wax is added to the furnish in order to reduce hygroscopicity and improve water repellency in the finished panels. Winistorfer et al. (1996) showed that edge thickness swelling decreased as wax level increased and that there was an optimum wax application rate that maximized water repellency. It is generally believed that a uniform distribution of small wax spots within the particleboard repels water penetration most effectively, but none of the literature reviewed described the relationship between the uniformity of wax distribution and the thickness swelling of panels.

Acoustic emissions (AE) are elastic waves generated by the rapid release of energy from localized sources within a material (ASTM E1316-94 1994). Beattie (1983) pointed out that acoustic emission signals have the same random character as the AE events from which they are generated. Although similarities exist between burst signals from a given test, the two signals are seldom identical in their characteristics. In general, signal counts have been commonly used for AE tests involving wood or wood-based composites. AE counts are the simplest parameter to measure and are defined as the number of times the AE signal exceeds a certain threshold level. The relationship can be expressed as (Beattie 1983):

$$N = \frac{\omega}{2\pi\beta}\ln\frac{V_0}{V_t} \qquad (2)$$

where

V_t = electrical signal voltage (millivolt)
V_0 = initial peak voltage (millivolt)
β = damping constant (1/second)
ω = angular frequency (radians/second)

The use of AE to study wood has a fairly long history. Miller (1963) used a microphone to detect the sound emissions generated from wood, and Porter (1964) was the first to use a piezoelectric crystal transducer to measure emissions from wood cleavage.

AE were used by Rice and Kabir (1992) to investigate the interaction of pine, redwood, and yellow-poplar with three different types of solvents. The results showed a relationship between the level of AE counts and the amount of swelling. Rice and Peacock (1992) measured AE counts from cyclic wetting and drying of southern yellow pine. The analysis showed that the amount of microfracturing caused by swelling pressure increased the void space for water penetration and decreased the AE level with each cycle.

Beall (1986) used AE to detect the influence of moisture content on particleboard under cyclic moisture conditions. His tests revealed that AE events always occurred in the process of desorption and only AE activity occurred in the process of absorption at the first exposure. The peak in AE event rate was achieved very early in the exposure, at about 14% full thickness swelling. The AE event rate then dropped at a linear rate with an increase in thickness swelling. The data indicate that most bond fracture occurs very early in swelling.

METHODS AND MATERIALS

For reasons discussed in the Results section, the experiments consisted of both preliminary tests and experiments designed to fulfill the objectives outlined above. The preliminary tests were designed to measure acoustic emissions levels from wood composites with and without resin and to assess the differences in sorption characteristics between MDF and particleboard.

The first preliminary AE tests were done using commercially prepared MDF and particleboard and boards pressed without resin made in the University of Maine Laboratory. This testing was designed to determine whether the presence of resin bonds was crucial to the development of acoustic emissions in wood-based composites. Twenty-four MDF and 24 particleboard samples were tested; half of the samples from each composite type were unresinated. The MDF fiber was prepared from mixed northern hardwoods, and the particleboard was made from a combination of southern yellow pine (about 80% by weight) and mixed southern hardwoods. The raw material used for the laboratory boards was supplied by the companies that provided the panels.

The target density of the MDF was 720 kg/m^3 and the particleboard target density was 800 kg/m^3 to match the density of the commercially prepared boards. Since the fibers were unresinated, the target thickness was only 0.3 centimeters. The mat was pressed at 182°C and an applied load of 9,070 kg. Press time was 10 min. After pressing, samples measuring 2.54 cm × 2.54 cm × 0.3 cm were cut from the boards. Samples were also taken from commercially prepared composites with resin levels of 8.3% (MDF) and 8.5% (particleboard). The commercially prepared samples of MDF and particleboard were machined to a thickness of 0.3 cm to match the unresinated samples. All of the samples were dried in a vacuum oven overnight at 49°C and 500 mm Hg vacuum. The AE test system parameters and protocols are described below for all tests.

A second series of preliminary experiments were done to obtain a general idea of the sorption characteristics of the boards being tested. Samples of MDF and particleboard were machined into samples measuring 3.8 cm wide and 25.4 cm long. All samples had a thickness of 1.58 cm. A total of 6 samples were tested. Prior to absorption testing, two edges of each specimen were fully coated using wax, so that the moisture uptake would occur only for the upper and lower surfaces and a single end. After the wax coating dried, the six samples were vertically immersed in distilled water to a depth of 12.7 cm. After 2 hours, each sample was sliced into 16 small pieces starting from the bottom with a length of 0.4 cm. After drying, the moisture content of each slice was calculated.

Two test protocols were used to fulfill the primary objectives of the research. First, acoustic emissions were measured from samples of MDF and particleboard with two different resin levels while the samples were undergoing swelling. The tests were repeated with samples having three different wax levels. Profile density measurements were also done from separate samples during each test series. The experimental design is shown in Table 1.

A total of 120 MDF and particleboard panels, each measuring 0.6 × 0.6 meters, were used. The panels were supplied by two commercial manufacturers[1]. The thickness of all panels was 1.58 cm.

For the resin level tests, the nominal density of the MDF panels was 769 kg/m^3 and the resin levels were 8.3 and 9.3%. The wax level was 0.58%. For the wax level tests, the nominal density was 769 kg/m^3 and the resin level was 8.2%. The wax levels were 0.5, 1.0 and 1.5%.

The particleboard had a nominal density of 800 kg/m^3 and a wax level of 0.2%. The resin levels were 6.5% and 8.5%. For the wax level

TABLE 1. *Design of the experiments.*

Test type	Test[1]	Board type[2]	Level[3]	Replicate	Total samples
Resin level	2	2	2	36	288
Wax level	2	2	3	36	432

[1] AE, and density profile tests.
[2] MDF and particleboard.
[3] 8.3% and 9.3% resin levels for MDF and 6.5% and 8.5% for particleboard. Wax levels of 0.5%, 1.0% and 1.5% wax levels for both MDF and particleboard.

[1] The MDF was supplied by Norbord Industries Inc. The particleboard was supplied by Willamette Industries Inc.

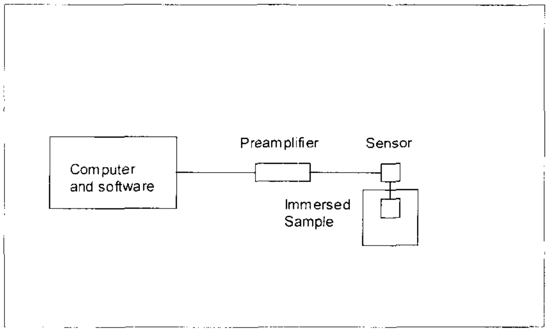

FIG. 1. Schematic of acoustic emission test system.

tests, the density was also 800 kg/m^3, the resin level was 6.50% and the wax levels were 0.5, 1.0 and 1.5%.

Three hundred and sixty samples, measuring 2.54 cm by 2.54 cm, were prepared for the AE tests. An equal number were prepared for the density profile tests. All samples were kept in a conditioning chamber at 32°C and 29% RH (5.7% EMC) until their weight was stable before testing.

A LOCAN AT System[2] (Fig. 1) Model 8900 was used to measure acoustic emissions. Piezoelectric transducers (PAC Model R15), resonant at 150 kHz, were used to monitor the acoustic emissions. Sensors were mounted on a waveguide and held with a light clamping mechanism. A thin layer of grease was used as a couplant. As recommended by the manufacturer and determined by the results of a series of preliminary experiments (Wang 1999), a total gain of 80 dB (reference 0 dB = 1 mV) was used, which included a preamplifier gain of 40-dB. The measurement threshold was set at 40 dB. Distilled water was used as a media to induce swelling.

After drilling a small hole to accommodate the waveguide, the samples were weighed and measured. The samples were then mounted on the T-shaped waveguides and immersed in water (Fig. 1). The AE test was started immediately. The duration for all AE tests was 120 min. After each test was finished, the total number of AE counts were recorded and the weight and dimensional size of each sample were remeasured.

[2] Physical Acoustic Corporation. Princeton, New Jersey, U.S.A.

RESULTS

Based on the information in the Introduction and in the Background sections, a number of criteria necessary for the success of the proposed approach are either evident or can be inferred. They include:

1. The composite must have a microstructure, either within the wood or between the particles/fibers, where swelling pressures can develop from water vapor.
2. The swelling pressures generated within the composite must have sufficient magnitude to create a dislocation within the wood or to fracture the bonds between the wood particles or fibers.
3. The materials within the composite must be sufficiently stiff to fracture or must dislocate in such a way as to generate a stress wave.
4. The generated stress wave must have sufficient energy to be sensed via the monitoring equipment and
5. The equipment used must be capable of capturing the sensor response.

Because of the random nature and intensity of the stress waves generated during the wood/water vapor interaction, it is not possible to capture all of the stress wave activity or to isolate with certainty the sources of the acoustic emissions. However sufficient information can be gained to determine trends and probable causes.

The equipment issues in items 5 and 6 were addressed through a series of tests with varying sizes of MDF and particleboard. Those tests used equipment and experimental parameters derived from experiments or based on the authors' experience. The final parameters used were a compromise that allowed measurement of both the particleboard and MDF emissions under the same circumstances (Wang 1999).

The first series of preliminary tests using resinated and unresinated boards was designed

TABLE 2. *Summary and results from the unresinated and resinated samples.*

	Resin levels (%)	# of samples	Avg. AE counts	SD
MDF	0	12	55	7.62
	8.3	12	885	173.20
Particleboard	0	12	25	8.6
	8.5	12	510	152

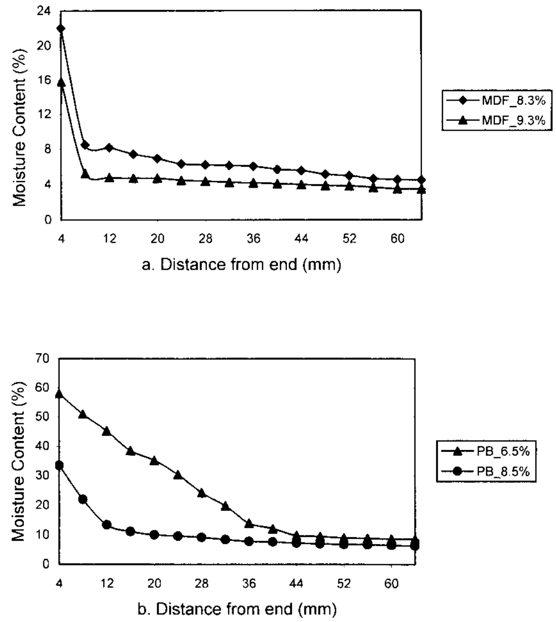

FIG. 2. a. Moisture absorption at two different resin levels: a. MDF and b. Particleboard.

to isolate, at least partially, the effect of resin on the production of acoustic emissions. Indirectly, the tests were also an indicator of both swelling pressure development and of microstructure. The approach may also reflect the effect of the stiffness of the composite since the level of measurable emissions is likely to decrease as the wood gains moisture and softens. A summary of the results is shown in Table 2. The AE counts from the MDF with resin were 16 times more than the AE counts from MDF without resin. Similarly, the resinated particleboard had, on average, over 20 times more counts than the unresinated board.

Resin bonds within the composites not only serve to keep fibers firmly together but impede liquid water absorption as well. As water vapor diffuses into the composites, swelling pressures develop in accord with Eq. (1) and swelling occurs. The swelling pressures cause fracturing of the resin bonds and the dislocation of the wood fibers that leads to acoustic emissions.

Within the unresinated boards, ligneous bonding can occur under the high temperature and pressure conditions used to manufacture the composites. However, the ligneous bonds are generally weak, and the composites without resin do not allow high swelling pressures to develop. Therefore, only a few AE counts were recorded during the tests. Clearly, the presence of resin helps to define the microstructure, affects the development of swelling pressures, and promotes the generation of AE.

The moisture absorption characteristics of MDF from the second group of preliminary tests are shown in Fig. 2a. The moisture content at the edges is very high in each case shown and then drops rapidly. During the process of preparing the samples of MDF, some damage occurred to the edges of the sample allowed liquid water penetration during the initial immersion. Moisture contents from other slices show a continuous reduction in each depth.

The pattern of Fig. 2a reveals that liquid water does not readily penetrate the MDF and that moisture transport is primarily by diffusion. Figure 2a confirms that the internal structure permits diffusion of vapor but limits liquid water entry. In general, higher resin levels result in slightly lower moisture content gains in a given time period, a further indication that resin affects moisture absorption.

The preliminary tests for moisture absorption in the particleboard (Fig. 2b) showed clearly different patterns than that of the MDF, and the pattern suggests that liquid water penetrates the composite. The sorption patterns also illustrate that particleboard is likely to have either more or larger void spaces than does MDF. The presence of void spaces in particleboard provides many passages for liquid water to penetrate the composite in a short

TABLE 3. *Average density and moisture content gain from the MDF and particleboard samples.*

	Medium density fiberboard					Particleboard				
	Resin level (%)		Wax level (%)			Resin level (%)		Wax level (%)		
	8.3	9.3	0.5	1	1.5	6.5	8.5	0.5	1	1.5
Average density (kg/m^3)	758	764	772	769	771	803	821	803	800	798
Average MC change (%)	10.5	8.5	9.1	8.4	7.5	12.6	12.1	12.6	11.4	11.2

time. The presence of liquid water does not lead to the development of swelling pressures that eventually cause acoustic emissions. Figure 2b also shows that the higher resin levels in particleboard result in lower moisture contents in a given time period.

Summary results of the density and moisture content changes for the commercially prepared MDF are shown in Table 3. The average AE counts and their standard deviations for MDF are graphed in Fig. 3a. The graph clearly indicates that MDF with a lower resin level produced, on average, more acoustic emission counts than MDF containing higher resin level. The AE counts were compared using a t-test, and the differences were significant ($P \approx 0$).

The commercially prepared MDF corroborated the results of the preliminary tests whereby the resin content was shown to be a factor affecting the number of acoustic emissions recorded during immersion. There are probably three main reasons for the differences in AE level shown in Fig. 3a. First, the resin level changes the microstructure of the composite leading to more microvoids wherein swelling pressures can develop but requiring more time for diffusion to occur. Similarly, the higher resin levels probably allowed less water vapor sorption compared with the MDF with a lower resin level (Table 3). Thus, less water vapor sorption may occur leading to less swelling pressure and bond failure or tissue movement. Finally, higher resin levels lead to significantly more bonds per cubic centimeter requiring higher swelling pressures to cause fracture. Accordingly, fewer acoustic emissions are generated at the higher resin level.

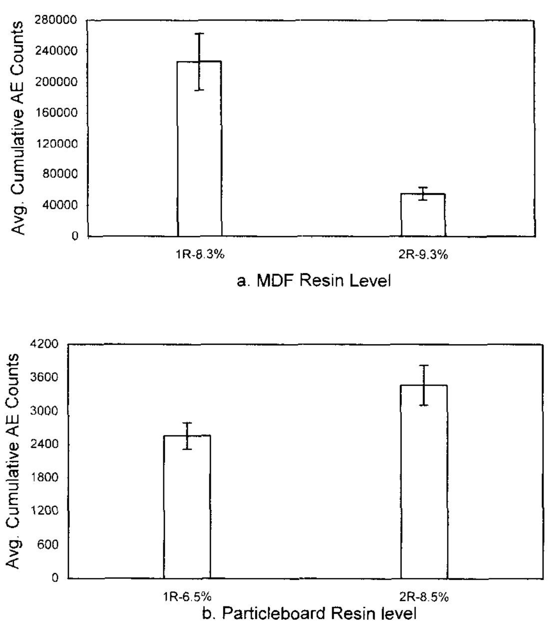

FIG. 3. AE responses at two different resin levels: a. MDF and b. Particleboard.

The COV (coefficients of variation) of the AE counts were calculated as 32% (8.3% resin) and 29% (9.3% resin). The causes of the high COV cannot be isolated using the experimental design but may be the result of factors such as resin droplet size, resin distribution, fiber orientation, processing factors, or the measurement technique.

The density values (Table 3) among the MDF samples at both resin levels were compared using a t-test and did not show a significant difference ($P = 0.36$). The correlation coefficients between density and AE counts were calculated as 0.001 (8.3% resin) and 0.2 (9.3% resin); both very weak.

A summary of the density and average moisture content changes for the particleboard samples is shown in Table 3. The results of the AE tests for particleboard are graphed in

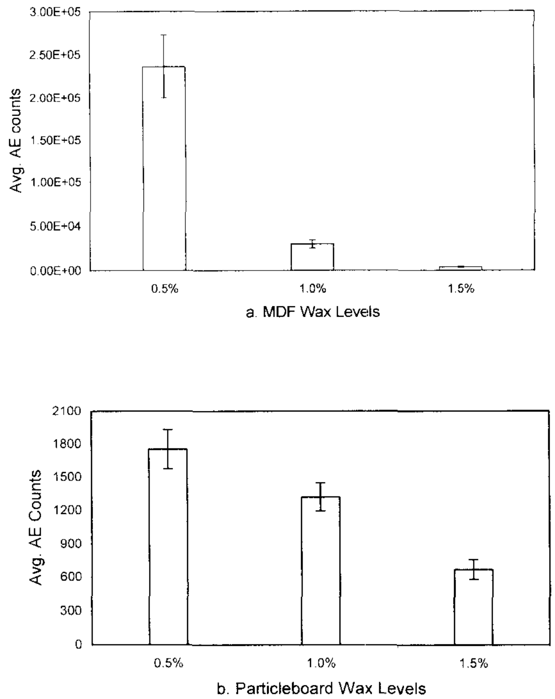

FIG. 4. AE responses at three wax levels: a. MDF and b. Particleboard.

Fig. 3b. The AE counts generated from the samples of particleboard increased as the resin level increased. The higher resin levels probably produced a greater number of microvoids that were accessible only to water vapor. The result was an increase in the swelling pressures in the higher resin level samples. The increased swelling pressure and number of bonds per cubic inch combine to produce a greater number of acoustic emissions during immersion. The difference in AE counts was statistically significant ($P \approx 0$). The correlation coefficients comparing AE and density were -0.28 and 0.28 for the particleboard having resin levels of 6.5% and 8.5%. The differences in density were not significant ($P = 0.07$) between the samples.

A summary of the density values and moisture content changes from the MDF with differing wax levels is shown in Table 3, and a graph of the test results is shown as Fig. 4a. The figure clearly shows that the AE counts decreased as the wax levels increased. A comparison (LSD test) showed that the differences among the three wax levels were significant ($P \approx 0$).

Assuming the spraying is uniform, increasing the percentage of wax should lead to a great number of fibers being coated. The wax coating on the fibers decreases the interaction of the water vapor with the wood. The effect is shown by the moisture content data in Table 3. A multiple comparison test supports the observation that the differences in moisture content among the MDF samples are significant ($P \approx 0$). The addition of wax effectively hinders the moisture penetration and influences the development of swelling pressures and the generation of acoustic emissions.

The relationship between the AE counts and density values was quite poor with correlation coefficients of 0.22, 0.01, and -0.19 for the three wax levels. A comparison (LSD) of density differences among the samples produced a P-value of 0.6, indicating that no significant differences existed among the density values.

The moisture content gains and density values from the particleboard samples at each wax level are shown in Table 3, and the average AE counts are graphed in Fig. 4b. The figure clearly shows that the AE counts decreased with an increase in wax level. A comparison (LSD) indicated that the differences were significant ($P \approx 0$).

The hydrophobic wax tends to coat the particles and increases moisture resistance. Higher wax levels coat more particle surface area than lower wax levels. Thus, higher wax levels may cause less water vapor sorption within the particles and result in smaller swelling pressures. The decrease leads to fewer acoustic emissions emanating from tissue movement within the particleboard with a higher wax level.

An important point that illustrates the relationship between AE, structure, and moisture content is shown by the average moisture content changes from the particleboard samples at each wax level (Table 3). In contrast to the MDF, a multiple comparison test (LSD) showed that the MC differences among the particleboard samples were not significant (P

= 0.11). The presence of void spaces allows liquid water to penetrate. However, the AE differences are not large among the three wax levels. Although moisture penetrates composites, swelling pressures are not causing tissue dislocation or bond fracture.

The correlation coefficients between AE counts and density values were calculated as −0.25, −0.17, and −0.04 for the three wax levels indicating the relationship was not strong. A multiple comparison test showed the differences in density between the particleboard samples at all three wax levels were not significant ($P = 0.45$).

When comparing the data from the MDF and particleboard tests several things are apparent. Table 3 and Fig. 3a clearly show that the resin levels in the MDF influenced AE counts and the moisture content changes. Specifically, the AE counts and MC changes both decrease with an increase in resin levels. Conversely, the AE counts increased with resin level in the particleboard even though the MC changes decrease within the MDF. As the water vapor concentration increases in the microvoid areas and in the cellular void spaces, swelling pressures build. The pressure makes the resin bonds fracture between fibers and the wood tissues dislocate. The result causes the abrupt stress changes that are the source of acoustic emissions. Higher resin levels in the MDF produce more resin bonds and affect the microstructure, the moisture sorption (less), and the bond strength (greater) of the composite. The MDF with higher resin levels allows less water vapor to penetrate compared with the MDF having a lower resin level in a given time period. Thus, less water vapor absorption and/or a greater number of bonds in the higher resin level MDF leads to fewer AE at higher resin levels.

The AE response from the particleboard samples is quite different from that of the MDF. As the resin level increases, the AE counts increase but the moisture content changes decrease. As shown by the preliminary experiments (Fig. 2b), the particleboard allows liquid water to penetrate. As resin levels increase, a greater number of resin bonds per cubic inch forms and increases the number of microvoids available for water vapor penetration within the volume. The combination of more bonds and microvoids increases the potential swelling pressures and decreases the moisture content gain (liquid water). The conditions lead to potential increases of swelling pressure and more acoustic emissions at the higher resin level.

Table 3, along with Fig. 4a and 4b, also shows that wax levels in both MDF and particleboard affect the AE counts and the moisture content gain of the composites. If the spraying is uniform, higher wax levels lead to a greater number of fibers or wood particles coated. The wax coatings impede the interaction of water vapor with the cell walls. Accordingly, the moisture content changes dropped as the wax level increased in both the MDF and the particleboard.

The patterns of moisture content change between the MDF and the particleboard as wax content increases illustrate an important point about the basic structure of the composites and the source of the acoustic emissions. The moisture content decreases in the MDF were statistically significant as the wax level increased, illustrating that a greater number of coated fibers resist moisture change and that the swelling pressures developed within the fibers was reduced or that the wax blocked water vapor access to the areas with microvoids. The pattern is quite different in particleboard. The changes in moisture content as the wax level increased were not statistically significant, suggesting that much of the moisture penetration occurs in the void spaces and not within the particles.

In general, a greater number of acoustic emissions are generated from the MDF samples than from the particleboard samples, while the moisture content gains are less in the MDF than in the particleboard. The differences highlight the internal structure and moisture penetration differences between the MDF and the particleboard.

CONCLUSIONS

Acoustic emission technology was successful in measuring the effects of resin and wax levels in both particleboard and MDF. The acoustic emissions are caused by the swelling pressures that develop in the wood-based composites and fracture the resin bonds or dislocate tissues.

The results clearly show that varying resin level significantly affected the number of acoustic emissions during a 2-hour immersion period. In the MDF, the average cumulative AE counts decreased as the resin level increased and the moisture content gain exhibited a statistically significant reduction. In particleboard, the AE increased in proportion to the resin content and the moisture content gains were not significantly different. The AE patterns in MDF and particleboard appear to be related to absorption characteristics and to microstructure.

The wax content of the composites showed pronounced influence on the AE counts. In the MDF, a higher wax level lowered moisture again and, consequently, reduced AE counts. Among the particleboard samples, the AE also decreased with increasing wax levels but the moisture content changes were not statistically significant, probably due to the presence of void spaces that were accessible to liquid water.

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REFERENCES

American Society for Testing and Materials, 1994. Standard terminology for nondestructive examinations. E 1316-94. ASTM, Philadelphia, PA.

Beall, F. C. 1986. Effect of resin content and density on acoustic emission from particleboard during internal bond testing. Forest Prod. J. 36(7):29–33.

Beattie, A. G. 1983. Acoustic emission, principles and instrumentation. J. Acoustic Emission 2(11):95–128.

Bennet G. A. 1969. An investigation of some properties of medium hardboard. Timberlab Paper No. 4. Forest Products Research Lab., Princes Risborough, Bucks., England.

Brown, F. L., D. L. Kenaga, and R. M. Gooch. 1966. Impregnation to control dimensional stability of particleboard and fiberboard. Forest Prod. J. 16(11):45–53.

Generalla, N. C., E. J. Biblis, and H. F. Carino. 1989. Effect of two resin levels on the properties of the commercial southern OSB. Forest Prod. J. 39(6):64–68.

Haygreen, J., and R. O. Gertjejansen. 1972. Influence of the amount and type of phenolic resin on the properties of a wafer-type particleboard. Forest Prod. J. 22(12):30–34.

Miller, D. G. 1963. Sounds generated by wood when under stress. Can Dep. Forest. Forest Products Res. Bulletin. Res. News 6:6–7.

Porter, A. W. 1964. On the mechanics of fracture in wood. Ph.D. thesis, State University College For., Syracuse University, Syracuse, NY.

Rice, R. W., and F. R. A. Kabir. 1992. The acoustic response of three species of wood while immersed in three different liquids. Wood Sci. Technol. 26:131–137.

———, and E. Peacock. 1992. Acoustic emissions resulting from cyclic wetting of southern yellow pine. Holz Roh- Werkst. 50:304–307.

Schneider, M. H., Ying H. Chui, and Stefan B. Ganev. 1996. Properties of particleboard made with a polyfurfuryl-alcohol/urea-formaldehyde adhesive. Forest Prod. J. 46(9):79–83.

Suchsland, O. 1973. Hygroscopic thickness swelling and related properties of selected commercial particleboards. Forest Prod. J. 23(7):26–30.

Skaar, C. 1988. Wood-water relations. Springer-Verlag, New York, NY.

Stillinger, J. R., and W. G. Coggan. 1956. Relationship of moisture content and flexural properties in 25 commercial hardboards. Forest Prod. J. 6(5):179–186.

Tarkow, H., and H. D. Turner. 1958. The swelling pressure of wood. Forest Prod. J. 8:193–197.

Wang, C. 1999. Evaluating the effects of resin level, wax level and refiner plated sharpness using acoustic emission technology. M.S. thesis, University of Maine, Orono, ME.

Winistorfer, P. M., Wei Xu, and Christopher M. H. 1996. Influence of three wax formulations and three application rates on thickness swell performance of southern pine flakeboard. Forest Prod. J. 46(3):63–67.