Influence of board density, mat construction, and chip type on performance of particleboard made from eastern redcedar

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Abstract

The purpose of this study was to investigate mechanical and physical performances of particleboard made from low-value eastern redcedar trees. The properties evaluated included bending strength and stiffness, swelling, surface hardness, and screw holding capacity as a function of processing variables (i.e., density, chip type, and board construction). Two types of chips (whole tree and pure wood), two types of mat constructions (single- and three-layer), and four different density levels (0.4, 0.5, 0.65, and 0.75 g/cm^3) were used in manufacturing the test panels. Board density and mat construction type were found to have major influences on board properties while chip type had no significant effect on the properties. The results showed that with some improvements in process parameters and processing techniques, low-grade eastern redcedar has a future as a particleboard furnish in the manufacture of marketable products.

Wood-based particleboard is manufactured in great quantities in the United States (U.S. Census Bureau 1999) and is primarily used in the furniture industry, which takes advantage of its strength and workability. Particleboard is also one of the major wood-based panels that can be fabricated using low-quality materials. The process of manufacturing whole-tree chip particleboard can make use of a majority of the tree anatomy, including the bark, small limbs, and even the needles (Maloney 1993). This process would allow converting low-quality material into value-added products, providing both environmental and economical benefits.

Eastern redcedar (*Juniperus virginiana* L.) is an evergreen ornamental and timer tree of the cypress family (Cupressaceae) native to poor or limestone soils of eastern North America (Wittwer 1985). It is one of the most widely distributed species due to its adaptability to various climatic conditions. The trees are usually of small diameter. Older growth redcedar trees of larger diameter often have deeply fluted trunks. The wood tends to be knotty, and the individual pieces of lumber that can be recovered are of small dimension. The wood's fine grain, its distinctive color, its pleasant aroma, and its ability to inhibit or repel insects that damage fabrics make it valuable for a specified end use (e.g., interior panels and closet-lining board). However, the irregular growth pattern of redcedar in most areas makes this species inefficient as a raw material for management or lumber manufacturing and in many states farmers are eligible for government subsidy payments to clear redcedar from their land (Hiziroglu et al. 2002).

Although the cultural and environmental influence of eastern redcedar is debatable, its fiber can surely provide a useful resource or supplement material to make wood-based composite panels.

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The value-added uses for eastern redcedar fiber could compensate for the cost of removing this species and eliminate disposal problems. The use of eastern redcedar for particleboard manufacturing would provide an economically feasible alternative for utilizing this low-quality species.

Hiziroglu et al. (2002) conducted an initial technical, economical, and marketing analysis for utilizing eastern redcedar chips for particleboard production. In their study, eastern redcedar chips with and without foliage were used to manufacture experimental particleboards at two density levels. The preliminary results showed that the whole-tree chipped eastern redcedar could be used to manufacture particleboard without having a significantly adverse influence on panel properties. However, for wood-based composites to become acknowledged and acclaimed as marketable materials, their mechanical and physical behavior must be fully characterized and understood.

The purpose of this study was to provide detailed information about the technical performance of low to medium density eastern redcedar particleboard manufactured through whole-tree chips and pure-wood chips. Specifically, mechanical and physical properties including strength, stiffness, swelling, surface hardness, and edge screwholding capacity as a function of processing variables (i.e., density, chip type, and board construction) were investigated and compared with ANSI A208.1 requirements for 1-M-3 medium density particleboard (640 to 800 kg/m^3).

Materials and methods

Small-diameter (average of 28 cm) eastern redcedar logs grown in Oklahoma were chipped in the field (Hiziroglu et al. 2002). Two types of chips were collected in this study: whole-tree chips including bark, branches, and needles and pure-wood chips without bark, branches, and needles. Both chip types were hammermilled separately through an 8-mm screen. For the construction of three-layer board, particles from pure-wood chips were further screened with a 2-mm screen to separate fine and coarse particles. Fines were used as furnish for the face layers and the rest was used for the core layer.

After being dried to about 4 percent moisture content (MC), particles were blended with 1 percent commercial wax emulsion and 7 percent commercial urea-formaldehyde (UF) resin (based on the ovendry wood particle weight) in a drum-type blender. For the three-layer panel, two UF resins with different curing speeds (slow and fast) were applied to the particles of the face and core layers. Mat forming was hand-performed into the forming box. The three-layer mat was formed in the order of face - core - face layers and the weight ratio of face to core was 60:40. All mats were pressed at a temperature of 180°C for six minutes. The average closing time between press contact with the top of the mattress and reaching the target thickness was about 40 seconds. The dimension of each panel after pressing was about 55.88 cm long by 50.80 cm wide by 1.27 cm thick. The target densities were 0.40, 0.50, 0.65, and 0.70 g/cm^3 for single-layer panels; 0.65 g/cm^3 for three-layered panels; and 0.50 and 0.65 g/cm^3 for single-layer panels made from whole-tree chips. Three replications with each board type were produced.

All panels were cooled and conditioned under the room conditions (25°C and 65% relative humidity [RH]) for one week after hot pressing. Specimens were then carefully prepared and tested following the instruction of the ASTM Standard D-1037 (ASTM 1999). For each panel, there were:

- two specimens (5.08 by 5.08 cm) for measuring the vertical density profile (VDP) on a QMS density profiler;
- four specimens (35.56 by 7.62 cm) for determining the bending modulus of elasticity (MOE) and modulus of rupture (MOR);
- four specimens (5.08 by 5.08 cm) for measuring internal bond (IB) strength;
- four specimens of 7.62 by 10.16 by 2.54 cm (two samples laminated together as recommended in ASTM D-1037 for particleboards of less than 25 mm thickness) for determining the surface hardness and the face screw withdrawal resistance perpendicular to the surface;
- two specimens (2.54 by 27.94 cm) for the measurement of linear expansion (LE); and
- one specimen (15.24 by 15.24 cm) was prepared to evaluate thickness swelling (TS).

Surface hardness was determined by measuring the maximum load applied until a ball with a 1.128-cm radius was embedded to the depth of its radius on the surface of the board. In particular, a load-indentation curve was recorded for the determination of the hardness modulus to be compared among the specimens with various densities. For the face screw withdrawal resistance test, a 2.54-cm-long No. 10 type AB sheet metal screw was threaded into each double-thickness specimen following a leading hole (0.32-cm diameter) with a penetration depth of 1.7 cm. For LE measurement, special rivets with cross marks on their heads were driven into the specimen with a longitudinal distance of 25.4 cm apart. A specially designed LE machine was used to accurately measure the distance change between the two reference nails before and after conditioning (ovendry to 24-hr. water soaking). TS was measured at the 25.4-mm positions from each of the four edges and at the center for a given sample after the samples were soaked for 24 hours according to the ASTM standard (ASTM 1999).

Results and discussion

Mechanical and physical properties of particleboards made from eastern redcedar under various specifications (i.e., different chip types, densities, and constructions) are shown in **Table 1.** The results of the statistical analysis of variance (ANOVA) (with a = 0.5) on process parameters effects (both single and two factors) are shown in **Table 2.** A detailed discussion of each property follows.

Mean density and density profile

Actual mean panel specific gravity varied from 0.42 to 0.80 kg/m^3 **(Table 1).** This led to panel compaction ratios of 0.88 to 1.67 based on 480 kg/m^3 density for eastern redceder at about 7.5 percent MC. Malony (1 993) stated that a compaction ratio of 1.3 is a good estimate of the degree of compaction needed to consistently make well-bonded boards. Thus, the lower two compaction ratios are below what would be considered adequate and the later two are adequate according to the Malony's guideline. The highest compaction ratio used in this study was reasonably close to the maximum obtainable with this raw material for production of medium density particleboard.

Table 1.–Properties of eastern redcedar particleboards.[a]

Chip and board type[b]	Specific gravity[c]	MOE[d]	MOR[d]	IB[d]	Hardness[d]	Screw holding[d]		Thickness swelling	
		(GPa)	------ (MPa) ------		-------- (N) --------				
Whole-tree (WT)									
WT1B	0.603 (0.038)	1.35 (0.33)	9.55 (2.55)	0.58 (0.13)	2,995.9 (650.7)	1,072.1 (224.4)	1.11 (0.12)	18.0 (3.2)	19.5 (3.9)
WT1C	0.683 (0.038)	1.61 (0.25)	11.12 (1.87)	0.71 (0.07)	4,003.3 (544.9)	1,260.3 (201.9)	1.19 (0.19)	20.9 (3.2)	25.3 (2.2)
Pure-wood (PW)									
PW1A	0.42 (0.03)	0.51 (0.16)	3.08 (3.75)	0.38 (0.14)	1,730.7 (278.3)	676.4 (167.6)	0.67 (0.05)	13.6 (3.3)	15.2 (2.5)
PW1B	0.518 (0.038)	1.53 (0.35)	10.50 (1.91)	0.54 (0.19)	2,494.1 (437.1)	935.2 (253.8)	0.84 (0.04)	17.0 (4.1)	19.8 (2.9)
PW1C	0.668 (0.026)	1.78 (0.22)	11.84 (1.63)	0.91 (0.09)	3,913.1 (730.1)	1,383.8 (277.3)	1.14 (0.05)	21.9 (2.3)	25.0 (1.6)
PW1D	0.804 (0.023)	2.62 (0.14)	16.78 (3.29)	0.79 (0.10)	5,951.5 (533.1)	1,902.2 (209.7)	0.98 (0.09)	25.3 (2.6)	29.0 (2.9)
PW3C	0.711 (0.051)	1.896 (0.32)	14.13 (2.27)	0.934 (0.13)	4,997.0 (985.9)	1,044.7 (246.0)	1.15 (0.07)	25.3 (3.3)	25.9 (4.7)

[a] Values in parentheses are standard deviations.
[b] WT =whole tree; PW = pure wood; 1 =single layer; 3 = three layer; A - D is target density A: SG = 0.4; B: SG = 0.5; C: SG = 0.65; and D: SG = 0.75.
[c] Specific gravity is based on ovendry weight and volume at 7.5 percent MC.
[d] Properties measured at a mean MC of 7.5 percent.
[e] Tested from ovendry to 24-hour water soak.

Table 2. –ANOVA results ($\alpha = 0.05$).[a]

Property	Modulus of elasticity		Modulus of rupture		Internal bond	Hardness	Edge screw withdrawal resistance	Linear expansion		Thickness swelling
	WT chips	PW chips	WT chips	PW chips				WT chips	PW chips	
Density	S	S	S	S	S	S	S	NS	S	S
Chip type	NS		NS		NS	NS	NS	S		NS
Construction[b] position	S		S		S	S	S	NS		S
(edge:center)										S

[a] WT = whole-tree chips; PW = pure-wood chips; S = significant; NS = not significant.
[b] Comparison between single- and three-layer boards.

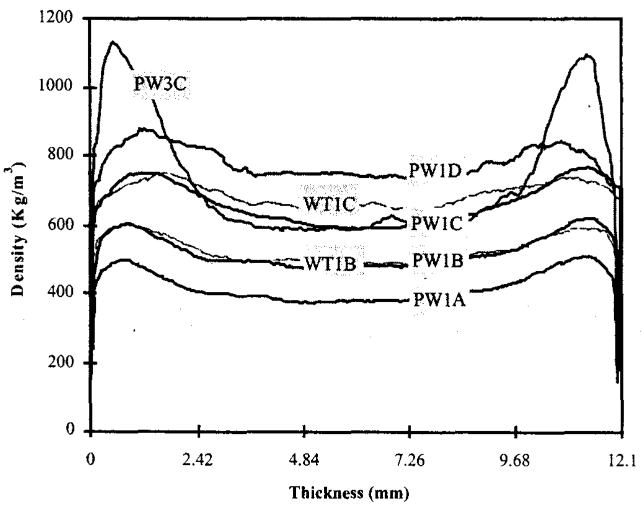

Figure 1. – Vertical density profiles of eastern redcedarparticleboard from various board types.

Figure 1 shows the vertical density profiles (VDPs) for different particleboards (see footnote b of **Table 1** for board classification). For single-layer particleboards, the patterns of VDP were similar despite different mean panel densities. It seems that chip types did not affect the density profiles significantly. However, the three-layer board showed a more distinctive U-profile of density due to fine particles on the panel surfaces. The fine particles were easy to press at a high temperature and formed a higher density (Kelly 1977). Generally speaking, a flatter VDP from a single-layer board could achieve good dimensional properties while distinctive U-shape density profiles could produce good bending properties. Development of panels with various density gradients as affected by pressing conditions was more complicated and beyond the scope of this study.

Mechanical bending properties

The average MOE and MOR values with their standard deviations (SD) are summarized in **Table 1.** MOE and MOR in all groups increased with panel mean density. The overall MOE and MOR values were consistent with 7 percent resin usages, which was most likely rather low for grade 1-M-3 boards. The particular values did not meet the ANSI A208.1 requirement for 1-M-3 grade particleboard (i.e., 2,750 MPa); and only the MOR value in the PW1D group (pure wood, single layer, and highest density panels) barely satisfied the ANSI A208.1 requirement (i.e., 16.50 MPa). Although the mechanical properties were relatively low, it is expected from this study that high resin usage or using high performance resin (i.e., MDI resin) would produce particleboards

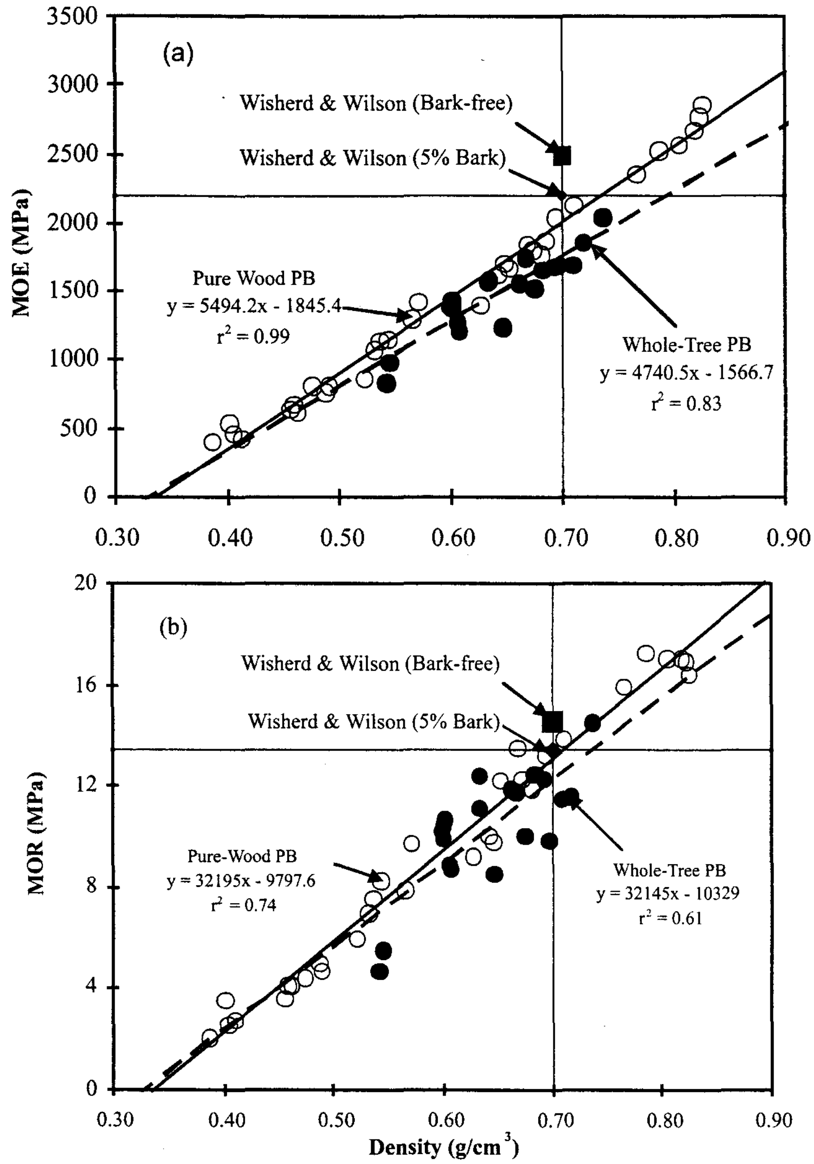

Figure 2. – Density effect on (a) bending MOE and (b) MOR of eastern redcedar particleboard with two different types of chips.

with acceptable performances. Meanwhile, adjusting pressing conditions such as practicing the densification at the face in the early pressing step and using high resin content in the face layers could improve bending properties significantly (Moslemi 1974).

Density was one of the most import factors that affected mechanical properties of particleboard (1984). In this study, reasonably good correlations (r^2 ranging from 0.61 to 0.99) were found between static bending properties and density. **Figure 2** shows the density effect on MOE and MOR of eastern redcedar particleboards made from two different wood chips. The high correlation between density and mechanical properties indicated that increasing density could improve mechanical performance. As expected, three-layer particleboards demonstrated significantly better bending properties than the single-layer boards due to the higher density in the face layers.

Also shown in **Figure 2** are experimental data from Wisherd and Wilson (1979) for particleboard made of pure wood and material containing 5 percent bark with 6 percent UF resin. At the 0.7 g/cm^3 density level, the MOE data from Wisherd and Wilson's study were better than the current values, while the MOR data from the two studies were reasonably close. The results reflect the differences in wood species, particle geometry, and resin content level used.

It was interesting to observe that the regression lines between densities and mechanical properties of particleboards made from two different chips were so close that further statistical analysis results **(Table 2)** concluded that there was no significant effect of chip type on MOE and MOR. This observation is somewhat in contrast to the findings from Muszynski and McNatt (1984) and Wisherd and Wilson (1 979). The reason was probably due to the low particle quality and low weight percentage of bark and foliage in the whole-tree chips used. It is possible that the hammer-milled wood particles used in this study were of less desirable geometry and/or condition than the wood particles used by the previous researchers as their base materials. With a base material that makes boards with relatively good properties, contaminates (i.e., bark) have a greater potential to diminish those properties. Alternatively, the mass portion of bark and foliage in the whole-tree chips might have been lower than the mass proportions of bark that previous researchers added to their panels.

IB strength

Although most average MOE and MOR values were lower than the ANSI A208.1 requirement for 1-M-3 grade particleboard, IB data, on the other hand, showed surprisingly results. **Table 1** shows that most average IB values exceeded the ANSI requirement value (i.e., 0.55 MPa) except the boards made from pure-wood chips at the two lowest target densities. Again, no significant influence of the chip type on IB values **(Table 2)** was observed. This was encouraging information on full utilization of low-grade eastern redcedar, because barks and needles from the whole-tree chips did not affect IB performance greatly. The two-factor ANOVA **(Table 2)** showed that there was a significant effect of density on IB performance. However, linear regression showed only r^2 = 0.43 statistical correlation between IB and board density **(Fig. 3).** The low 3 value was due to a large variability of measured IB at each of the target density levels.

Surface hardness

Surface hardness is an important measurement of surface resistant to indentation. It is measured by the maximum load required to embed a 1.128-cm ball to one-half its diameter. Two typical load-displacement curves are shown in

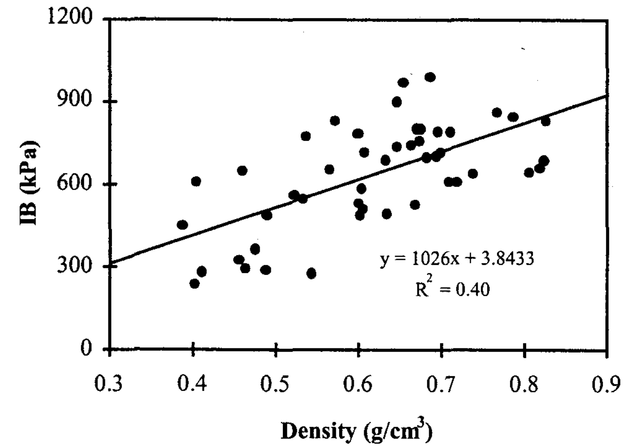

Figure 3. – Correlation between IB and board density for eastern redcedar particleboard.

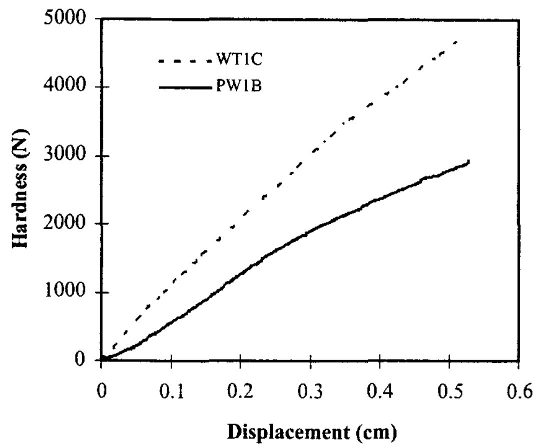

Figure 4. – Typical load-displacement curves for surface hardness test of eastern redcedar particleboard.

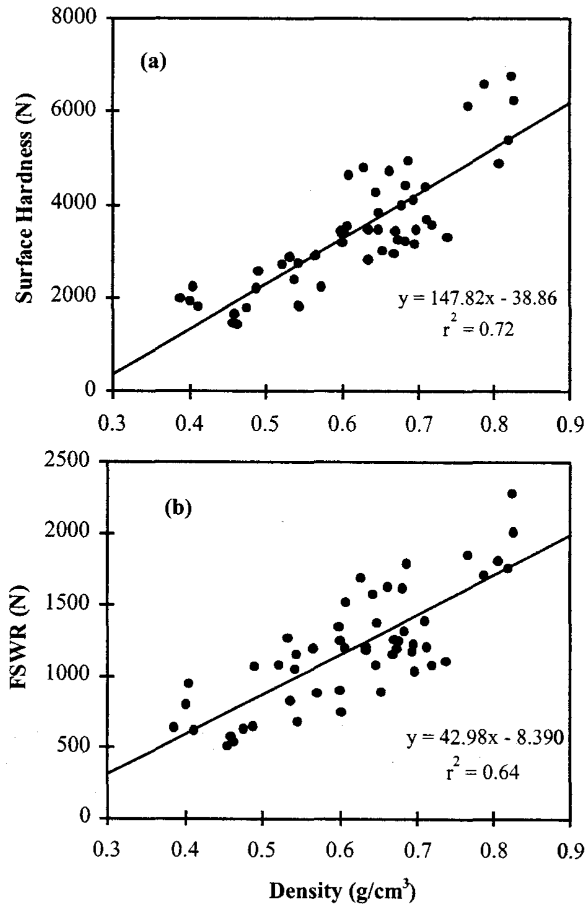

Figure 5. – (a) Surface hardness density and (b) face screw withdrawal resistance density relationship for eastern redcedar particleboard.

Figure 4 for eastern redcedar particleboard. The slope was defined as hardness modulus while the peak value was referred as surface hardness. No yielding point in those curves was observed. The surface hardness testing results **(Table 1)** showed that eastern redcedar particleboard had good surface hardness performance with average values in all groups, but the lowest density group outperformed the ANSI requirement for grade 1-M-3 (2,222.6 N). As expected, density (especially surface density) played an important role in surface hardness. A moderate linear correlation between surface hardness and density was observed **(Fig. 5a). Table 2** shows that there was no significant effect of the chip type on surface hardness.

Face screw withdrawal resistance

Face screw withdrawal resistance is commonly used to determine fastening quality of wood composites. **Table 1** shows that face screw withdrawal resistance values for most of the panel types were in the range or exceeded the ANSI requirement for grade 1-M-3 particleboard (1,111.3 N). The values were also similar with those of commercial particleboard performed by Cassens et al. (1994). There was no significant difference on face screw withdrawal resistance performance between the two types of chips. Screw withdrawal strength in wood varied with the square of wood density (USDA 1999). In this study, a moderate linear correlation (r^2 = 0.64) between face screw withdrawal resistance and board density was obtained **(Fig. 5b).** Such linear relationship between face screw withdrawal resistance and density was not reported in Kelly's literature review (1 977). Face screw withdrawal resistance was highly associated with mean panel density, VDP, and geometry of particle (Wong et al. 1999). The three-layer boards had face screw withdrawal resistance values in the range of the ANSI standard value even with low resin usage and panel density.

Dimensional stability

LE and TS were key parameters in describing dimensional stability of wood composites. Particularly, LE was considered as the control factor in qualifying the behavior of wood panels exposed to moisture (Wong et al. 1999). LE measured between the ovendry condition and

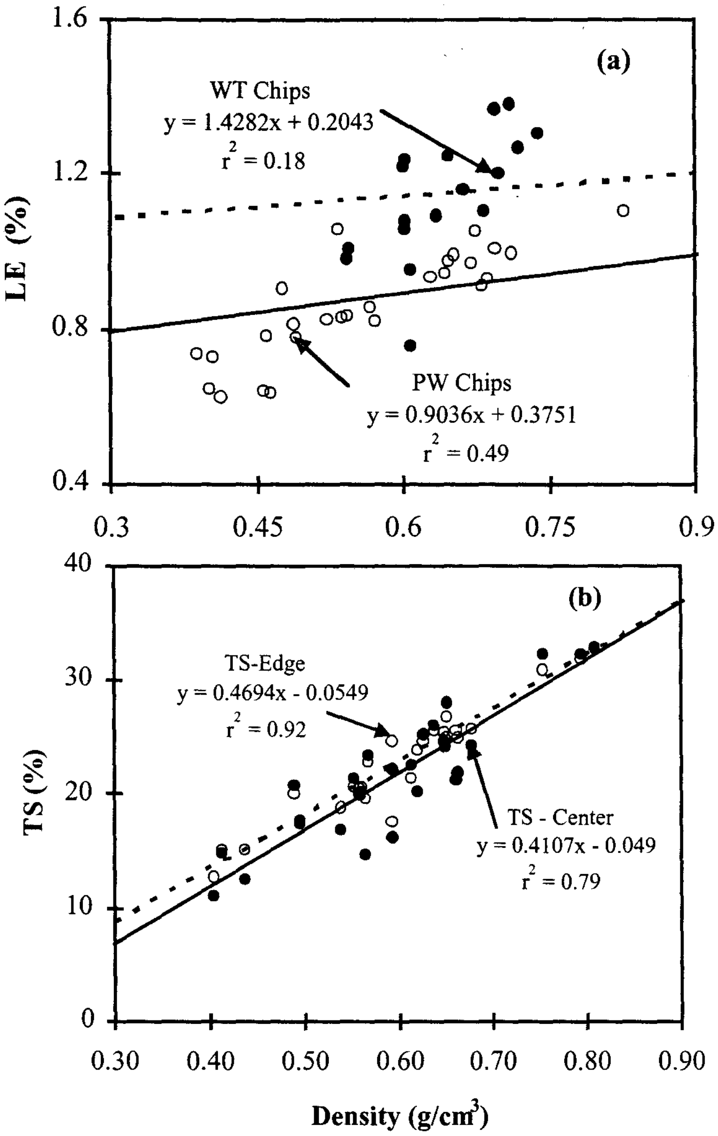

Figure 6. – (a) LE-density and (b) TS-density relationship for eastern redcedar particleboard.

24-hour water soak are summarized in **Table 1.** Compared with the LE value (0.5%) specified by ANSI for grade 1-M-3 with exposure conditions from 50 to 80 percent RH, most particleboards made from eastern redcedar with 1 percent wax content in this study had LE values that exceeded the ANSI standard value at the specific exposure condition used (i.e., ovendry to 24-hr. water soaking). This was due to the low UF resin content level and the more severe exposure conditions used. Statistical analysis indicated LE of eastern redcedar particleboard was significantly affected by chip type **(Table 2).** Particleboard made from whole-tree chips had poorer LE performance. Also, LE was much more dependent upon particle geometry and alignment rather than density (Kelly 1977). This was true in this study **(Fig. 6a)** and no statistically valid correlation between LE and board density was found (r^2 = 0.18 and 0.49 for whole-tree chips and pure-wood chips, respectively).

Both edge and center TS of particleboard made from eastern redcedar were examined in this study. TS at the sample edge and center showed a significant difference with edge TS slightly higher. All TS values exceeded the ANSI requirement for grade 1-M-3 particleboard (i.e., 8%). It needs to be pointed out that the pre-cured surfaces of the test panels were not sanded prior to the TS test, which led to higher TS values compared to sanded panels. The use of higher resin and wax loading levels will certainly improve TS properties. Compared with the particleboards of the same density range that were made from other species (spruce, pine, and beech) by Blanchet et al. (2000), similar TS was observed in this study for particleboard made from eastern redcedar. The TS values were not affected by chip type **(Table 2).** The result of this study indicated that the contribution of low-quality materials (such as bark, branches, and leaves) which increases the potential of board TS was confounded.

High-density boards possessed more compression set than lower density ones when both were made with the same wood furnish (Halligan 1970). It was believed that TS would increase with increasing board density. For example, three-layer boards showed higher TS in both locations than single-layer boards probably due to the presence of a high-density zone and fine particles. Good linear correlations between density and both TS values were obtained in this study **(Fig. 6b).**

Conclusions

Mechanical and dimensional performances of particleboards made from eastern redcedar were investigated in this study. Density was found to be the major factor that affected most mechanical and physical properties of the particleboard and fairly good linear correlations between panel density and various properties were obtained. Chip type (whole tree or pure wood) had no significant impact on most properties other than the LE performance. Three-layer particleboards made from eastern redcedar showed better performances than single-layer ones on most mechanical properties including bending MOE/MOR, IB, and surface hardness. With 7 percent UF resin usage, most of the boards did not meet bending stiffness requirements for 1-M-3 grade particleboard and only the highest density boards met bending strength requirements. Other properties (i.e., IB, surface hardness, and face screw withdrawal resistance) were reasonably acceptable compared with the ANSI standard. Improvements in process parameters (e.g., increasing resin usage and overall board density, or using structural quality resin) and processing techniques dealing with extractive off-gassing at the press and the high silica content of the material would help convert low-value eastern redcedar trees into a profitable and marketable particleboard product.

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