Effect of Compression Wood on Dimensional Stability of Medium Density Fiberboard

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This study evaluated the effect of compression wood on dimensional stability of medium density fiberboards (MDF) manufactured from fiber furnishes of pine (Pinus nigra Arnold var. pallasiana) containing compression wood. Two panel types were manufactured from two different compression wood (CW) portion / normal wood (NW) portions in the furnish, 75/25 and 10/90, respectively. Linear and thickness variations of the panels exposed to various relative humidites at 20 °C, linear expansion/contraction and thickness swelling/shrinkage, were measured according to the procedures defined by DIN EN 318 (2005) standard test method. Panels made from fiber furnish containing 75% the CW had higher linear expansion and linear contraction values with an average value of 0.286% and 0.247% than those of panels made from fiber furnish containing 10% the CW with an average value of 0.184% and 0.152%, respectively. As for thickness swelling and thickness shrinkage properties, panels made from fiber furnish containing 75% the CW had the thickness swelling and thickness shrinkage values with an average of 5.042% and 4.402% while panels made from fiber furnish containing 10% the CW had the values with 3.621% and 2.861%, respectively. Consequently, based on the findings obtained from this study, expansion and swelling properties of the MDF panels were negatively affected by compression wood increase.

Keywords compression wood, linear expansion, linear contraction, thickness swelling, thickness shrinkage, medium density fiberboard, dimensional stability
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1 Introduction

Medium density fiberboard (MDF) is one of the most rapidly growing composite panel products in forest products market (Ayrilmis 2007). The physical and mechanical properties of MDF are mainly dependent upon the properties of the raw materials (wood, binders, and other additives) and manufacturing parameters (Akbulut et al. 2004). When wood is considered as a raw material, wood fiber properties such as fiber structure and strength, anatomical and chemical properties of fiber, and fiber composition (percentages of whole and broken fibers and fines) are considered to be basic characteristics influencing fiberboard properties due to occupying a large portion of the total panel volume (Suchsland and Woodson 1991, Maloney 1977, Groom et al. 1999).

Compression wood is one of the most important raw material variables in wood based panel manufacturing such as particleboard, fiberboard, and flakeboard. Compression wood is of interest because its properties are considerably different from, and much less desirable than, normal mature wood (Timell 1986, Haygreen and Bowyer 1996, Bowyer and Smith 1998). In fact, compression wood has many of the same properties as juvenile wood. Its greatest drawback is its exceedingly high longitudinal shrinkage, which can attain 5–10%. Radial and tangential shrinkage, in contrast, are less than in normal wood (Timell 1986). The high longitudinal shrinkage is mostly a result of the large microfibril angle in the S_2 layer of the tracheids. Compression wood expands and contracts longitudinally much more than normal wood as a result of changes in the humidity of the atmosphere (Wloch 1975, Timell 1986). Such movements can cause pulling and loosening of fastenings, pulling of nails, and opening of joints.

As solid wood and other wood-based panels, fiberboard is a hygroscopic material; therefore, its moisture content depends on the relative humidity and temperature of the surrounding air (Ganev 2002). Because linear and thickness variations of fiberboard are critical in most applications, the maximum allowable dimensional change in such products is limited by standards (Vital et al. 1980). Linear expansion or contraction, in response to increased or decreased moisture content of the material, becomes important when large panel sizes are used or when the expansion is totally or partially restrained. The in-plane movements arised from increased or decreased moisture content of the panel can cause high internal stresses due to the restraint offered by fastening such as nails in construction. These stresses may be large enough to cause buckled panels, pushed-out nails, and separation of the panel from the structure (Wu and Suchsland 1996). The hygroscopic linear expansion in the plane of particleboards and fiberboards is of practical importance in the application of these materials as industrial core stock (Suchsland and Xu 1989). Expansion and contraction values of fiberboard, thus, become important design parameters.

Previous studies investigated water resistance of particleboard and fiberboard made from furnish containing compression wood (Gunther et al. 1972, Lehmann and Geimer 1974, Coleman and Biblis 1977, Akbulut et al. 2004). One of them reported that average thickness swelling value (24 hours of submersion in water) of MDF panels made from fiber furnish containing 10% CW content was 5.18%, while the same property of the panels made from fiber furnish containing 75% CW content was 6.07% (Akbulut et al. 2004). Based on the findings of these studies, water resistance of the panels was adversely affected by compression wood. This was attributed to some undesirable physical and anatomical properties of the compression wood tracheids such as the thick cell wall, the S_1 layer, the large microfibrillar angle in S_2 layer, spiral checks or fissures in the cell wall, and the presence of the helical cavities as well as chemical properties (Timell 1986). In addition, compression wood is harder and more brittle than normal wood because the rounded and thick-walled tracheids of compression wood, inflexible because compression wood about 10% less cellulose and 8–9% more lignin and hemicellulose than normal wood (Haygreen and Bowyer 1996). Therefore, grinding of compression wood particles by defibrator method could produce a high proportion of broken fiber fragments between defibrator discs, unable to bond together in the manner of intact fibers from normal wood in the panel manufacture. Fiber composition is a critical factor determining the properties of fiberboard (Suchsland and Woodson 1991). Shorter fibers and fiber fragments are disadvantageous since the contact length between fibers is diminished. In a previous study, thickness swelling of the panel due to water absorption was significantly affected by the fiber length (Ayrilmis 2000). Because of these reasons, compression wood is obviously inferior to normal wood for manufacture of fiberboard.

As mentioned above, the previous studies investigated only the water resistance of particleboard and fiberboard made from furnish containing some compression wood. An extensive literature search did not reveal any information about the dimensional stability of MDF made from furnish containing large amounts of compression wood, although various studies were performed on effect of juvenile wood on dimensional stability of wood based panels (Wasniewski 1989, Pugel et al. 1990, Ross et al. 1994, Geimer et al. 1997, Shi et al. 2005). Water resistance of the MDF panels used in the present study was determined by Akbulut et al. (2004). This publication provided valuable information about thickness swelling and water absorption of the panels made from compression wood after 24 hours submersion. However, MDF panels in service are generally exposed to changing relative humidity levels, unlike water submersion. For this reason, linear and thickness variations induced by a change in moisture under the influence of variations in the surrounding atmosphere, are great and have a marked effect on the permanence and serviceability of the MDF panel. Main objective of this study is to determine influence of the compression wood on expansion properties such as linear expansion and contraction, and swelling properties such as thickness swelling and shrinkage of MDF panels, at two different compression wood (CW) portion / normal wood (NW) mixes.

2 Materials and Methods

2.1 Materials

Eccentric pine stem woods (*Pinus nigra* Arnold var. *pallasiana* grown naturally in Turkey) containing large amounts of compression wood and normal wood were used to manufacture experimental panels (Fig. 1). The pine stems were harvested from slopes region of Kastamonu forests in Northern Turkey. The stems, all the same silvicultural treatment and altitudes 1000–1300 m of the forests, were between 25 cm and 40 cm in diameter. Compression wood was identified visually on the cross section of butt-end of the freshly cut logs. Compression wood was detected by color (reddish-brown) and wide growth rings contain a high proportion of latewood, and the contrast between earlywood and latewood on the cross section. A specially constructed ground glass plate was placed on the cross section, and total and compression wood areas were measured with a planimeter. Then, the stems were divided into logs of 1-m average length. In the logs that contained compression wood, ratios of compression wood and normal wood were determined from cross-section of butt-end of the log. The ratios of compression wood and normal wood were cal-

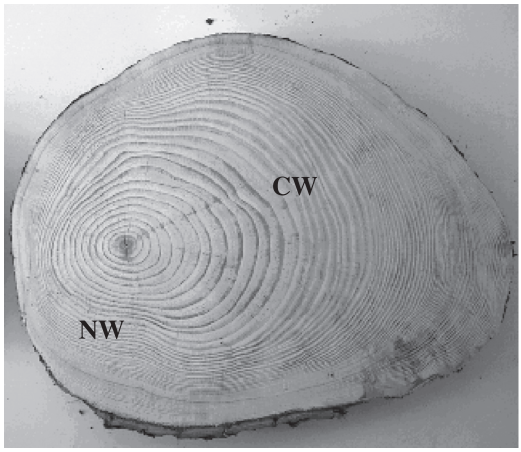

Fig. 1. Cross section of the leaning *Pinus nigra* Arnold var. *pallasiana* stem with compression wood (CW) and normal wood (NW).

Table 1. Composition of the experimental panels.

Panel type	Compression wood and normal wood portions of the panels	
	Compression wood (%)	Normal wood (%)
A	75	25
B	10	90

culated from percentages of area measurements on the cross sections. The compression wood and normal wood were not separated from each other in panel manufacturing. Table 1 presents portions of compression wood and normal wood of the experimental panels.

2.2 MDF Manufacturing

Experimental MDF panels (3660 mm × 1830 mm × 10 mm) were manufactured at SFC Integrated Wood Company located in Kastamonu, Turkey. A total of 8 panels, 4 for each type of fiber furnish, were manufactured. The chips having an average size of 20 mm × 25 mm × 5 mm were produced from round wood. Raw material was converted into fiber furnish in a *Sunds* defibrator using a steam pressure of 7.5 bar at a temperature of 178 °C for 5 minutes. The following were added to the fiber furnish: 1% wax, 0.8% NH_4CL as hardener, and 11% urea-formaldehyde resin. Mats with average moisture content of 10.5% were pressed at temperature of 205 °C for 220 seconds at a pressure of 3.7 N/mm^2. The panels were sanded with a sequence of 50, 60, 80 and 120 grit size following the cooling process. Air-dry density values of type A and B panels were found as 0.81 g/cm^3 and 0.79 g/cm^3, respectively, according to DIN EN 323 (1993).

2.3 Determination of Dimensional Stability

Dimension stability is the degree to which a material maintains its original dimensions when subjected to changes in temperature and humidity. The linear and thickness variations of the MDF panels were determined in conformance with DIN EN 318 standard (2005). According to DIN EN 318, linear and thickness variations of fiberboards, between two equilibrium moisture contents, are calculated as a percentage of the initial specimen length and thickness. The hygroscopic strain is determined at 20 ± 2 °C as the percentage change of the initial length and thickness recorded at equilibrium. The increases in length and thickness were monitored from 65% to 85% relative humidity in adsorption as defined in Table 2 (first regime: measure difference between second and third treatments) while decrease was monitored from 65% to 30% relative humidity in desorption (second regime: measure difference between first and second treatments) as defined in Table 2.

A total of 80 specimens with dimensions of 300 mm × 50 mm × 10 mm, 40 parallel and 40 perpendicular to the sanding direction of the panels, were tested for each panel type to determine linear and thickness variations. The linear and thickness variations were separately evaluated in two panel directions as defined in DIN EN 318 standard. The specimens were exposed at humidity until reaching equilibrium at two regimes: the first regime represented the change among consecutive relative humidities, 30%, 65%, and 85%, at 20 °C temperature; the second regime represented the change among consecutive relative humidities, 85%, 65%, and 30%, at 20 °C temperature, respectively (Table 2). The specimens were conditioned until constant weight and moisture content in a climate chamber for each treatment level. For this aim, 20 specimens parallel to the sanding direction of the panel were used for regime 1 and 20 for regime 2. The same procedure was applied to specimens perpendicular to the sanding direction of the panel.

Table 2. Two conditioning regimes of the specimens at the consecutive relative humidites.

Treatment order	First regime	Second regime
1	20 °C and 30% relative humidity	20 °C and 85% relative humidity
2	20 °C and 65% relative humidity	20 °C and 65% relative humidity
3	20 °C and 85% relative humidity	20 °C and 30% relative humidity

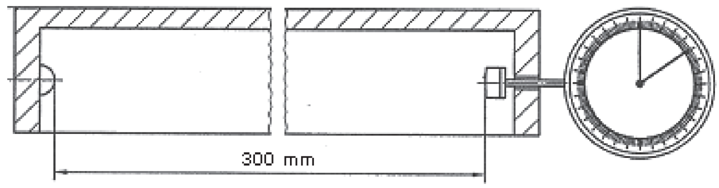

Fig. 2. Test apparatus used for measuring of expansion and contraction of the specimens. 300 mm refers to specimen length. (From DIN EN 318).

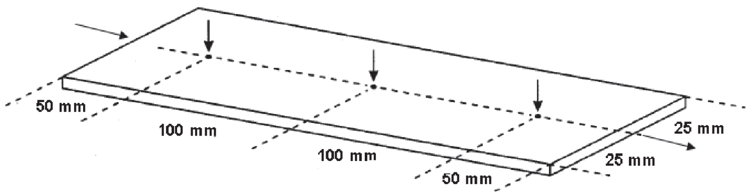

Fig. 3. Positions for measuring thickness and length variations.

2.3.1 Determination of Linear Expansion and Contraction

Linear expansion and contraction were calculated on the basis of the specimen initial length by using of the apparatus shown in Fig. 2 with an accuracy of ±0.001 mm using equipment according to the DIN EN 318 standard (Fig. 3). The linear expansion and contraction were calculated as follows:

$$LE_{65\text{ to }85} = (L_{85\_final} - L_{65\_initial}) \times 100 / L_{65\_initial} \quad (1)$$
(with using of regime 1 results)

$$LC_{65\text{ to }30} = (L_{65\_initial} - L_{30\_final}) \times 100 / L_{65\_initial} \quad (2)$$
(with using of regime 2 results)

where

$LE_{65\text{ to }85}$ = linear expansion after relative humidity (RH) change from 65% to 85%, based on the length measured at 65% RH (%)

L_{85_final} = final length of the specimen conditioned at 85% RH (mm)

$L_{65\_initial}$ = initial length of the specimen conditioned at 65% RH (mm)

$LC_{65\text{ to }30}$ = linear contraction after RH change from 65% to 30%, based on the length measured at 65% RH (%).

2.3.2 Determination of Thickness Swelling and Shrinkage

The thicknesses were taken at three points at the specimens medium width with an accuracy of ±0.001 mm (Fig. 3). Thickness swelling and shrinkage properties were calculated as follows:

$$TS_{65\text{ to }85} = (T_{85\_final} - T_{65\_initial}) \times 100 / T_{65\_initial} \quad (3)$$
(with using of regime 1 results)

$$TSh_{65\text{ to }30} = (T_{65\_initial} - T_{30\_final}) \times 100 / T_{65\_initial} \quad (4)$$
(with using of regime 2 results)

where

$TS_{65\text{ to }85}$ = thickness swelling after relative humidity (RH) change from 65% to 85%, based on the thickness measured at 65% RH (%)

T_{85_final} = final thickness of the specimen conditioned at 85% RH (mm)

$T_{65\_initial}$ = initial thickness of the specimen conditioned at 65% RH (mm)

$TSh_{65\text{ to }30}$ = thickness shrinkage after RH change from 65% to 30%, based on the thickness measured at 65% RH (%).

2.4 Statistical Analysis

t-tests (P = 0.05 confidence level) were conducted to evaluate the significance of the differences between the panel A and panel B type in terms of linear and thickness variations (Kalipsiz 1988).

3 Result and Discussion

Table 3 shows the results of linear expansion (LE), linear contraction (LC), thickness swelling (TS), and thickness shrinkage (TSh) of type A and B panels. Significant differences (p = 0.05) were found between the two panel types according to the t-test. Expansion and swelling properties of the type A panels were negatively affected by compression wood. LE, LC, TS, and TSh values of type A panels in two principle directions were significantly higher than those of type B panels. For parallel to the sanding direction of the panel, type A panels had higher LE and LC values with an average value of 0.286% and 0.247% than those of type B panels with an average value of 0.184% and 0.152%, respectively. As for TS and TSh properties, type B panels had the TS and TSh values with an average of 3.621% and 2.861% while type A panels had the values with 5.042% and 4.402%, respectively. U.S. standard (ANSI A.208.2-2002) was used here for comparison of linear expansion property since there was no established maximum performance requirement for MDF and HDF in European standards. LE value of fiberboard measured between 50% and 80% relative humidity should be maximum 0.30% according to ANSI A.208.2-2002 standard. LE values both of the type A and B panels did not exceed the maximum property requirement of 0.30% percent based on the ANSI standard.

The values of LE and TS were higher than LC and TSh at any level of relative humidity. As seen in Table 3, the average LE value parallel to the sanding direction of type A panels was 0.286% in relative humidity change from 65% to 85% (adsorption) while the average LC value of the same panel type was 0.247% in relative humidity change from 65% to 30% (desorption). A similar trend was seen in TS and TSh values of the panels. The average TS value parallel to the sanding direction of type A panels was 5.042% while the average TSh value was 4.402%. In wood and wood composites, the moisture adsorbed at high relative humidity exposure is never entirely released when re-drying to lower relative humidity levels (well-known hysteresis phenomenon) (Ganev 2002). TS and TSh values of type A and B panels were much higher than LE and LC values.

The peculiar behaviour of expansion and contraction in relation to compression wood for the test panels may be explained at the cellular level. Compression wood fibers are about 30% shorter than normal wood (Dinwoodie 1961). Fiber length has a strong effect of dimensional stability of fiberboard because longer and thinner fibers improve thickness swelling and linear expansion properties of fiberboard (Maloney 1977). Furthermore, the length of overlap between two fibers, which may be considered to be proportional to the relative

Table 3. Linear expansion/contraction and thickness swelling/shrinkage values of the experimental panels in two principle directions.

Panel type	Parallel to the sanding direction of the panel				Perpendicular to the sanding direction of the panel			
	$LE_{65\ to\ 85}$	$LC_{65\ to\ 30}$	$TS_{65\ to\ 85}$	$TSh_{65\ to\ 30}$	$LE_{65\ to\ 85}$	$LC_{65\ to\ 30}$	$TS_{65\ to\ 85}$	$TSh_{65\ to\ 30}$
	%							
A	0.286 a	0.247 a	5.042 a	4.402 a	0.277 a	0.254 a	4.948 a	4.368 a
	(4.133)	(13.565)	(5.584)	(11.907)	(5.205)	(4.574)	(11.97)	(13.082)
B	0.184 b	0.152 b	3.621 b	2.861 b	0.175 b	0.148 b	3.572 b	2.815 b
	(9.812)	(8.021)	(9.524)	(6.732)	(10.736)	(9.822)	(5.103)	(7.386)

Note: Numbers in parentheses are standard deviations. LE: Linear expansion LC: Linear contraction. TS: Thickness swelling. TSh: Thickness shrinkage. Homogeneity groups: same letters in each columns indicate that there is no statistical difference (P = 0.05) between the specimens according to the t- test. Each value represents the average of twenty specimens.

bonding area in the panel. As the length of overlap is shortened, the quality of the bond between two fibers is reduced (Suchsland and Woodson 1991). In addition, length-thickness ratio (slenderness) is one of the most significant factors affecting dimensional stability of fiberboard (Maloney 1977). In a previous study, it was shown that with increasing slenderness of fibers, thickness swelling of the MDF panel decreased (Ayrilmis 2000). Slenderness of normal wood tracheids is higher than compression wood tracheids due to the fact that compression wood tracheids is shorter. For these reasons, higher thickness swelling value of type A panels could be attributed to the shorter fiber length of compression wood.

Compression wood is chemically and anatomically different from normal wood, as mentioned previously. The proportion of cellulose is about 10% lower than in non-compression wood, and the proportion of lignin is correspondingly higher. The high lignin content of compression wood tracheids makes them hard, brittle, and inflexible, causing them to break rather than separate from one another on grinding (Timell 1986). This results in high proportion of broken fiber fragments between defibrator discs. In addition, compression failures profoundly affect the ultra structure of pine fibers involved, causing disruption of their individual cell wall layers. The ordered arrangement of the cellulose micro fibrils is disturbed, and it is possible that the middle lamella is also affected (Timell 1986). A damage or lacking in fiber quality causes a comparatively high linear expansion in fiberboard, as seen in the compression wood tracheids (Maloney 1977).

Microfibril angle in S_2 layer is a major factor determining both longitudinal and volumetric shrinkage in compression wood. Slope of microfibrils in the S_2 layer is about 45 degrees from the vertical in compression wood while about 20 degrees for normal wood (Haygreen and Bowyer 1996, Bozkurt 1992). The large longitudinal shrinkage of compression wood has been attributed to the large microfibril angle in S_2 layer, in many studies (Shrinkage… 1952, Hale 1957, Rak 1957, Foulger 1966, Preston 1968). Compression wood shrinks and swells considerably along the grain with changes in moisture content, due to an abnormally high microfibril angle in the S_2 layer of the cell wall (Bowyer and Smith 1998). Shrinkage may be as great as 6% to 7%, and is commonly 1% to 2%. Higher linear contraction in type A panels as compared to type B panels was attributed in part to anatomical differences in cellulose fibril angles of the compression wood tracheids.

Boyd (1977) pointed out that factors other than the microfibril angle may also influence the swelling and shrinkage behaviour of compression wood. Such factors could include the thick cell wall, the S_1 layer, the large microfibrillar angle in S_2 layer (the orientation of the micro fibrils in S_2 layer), the relative proportions of the S_1 and S_2 layers, spiral checks or fissures in the cell wall, and the presence of the helical cavities (Boyd 1977). It is interesting to note in this connection that the proportions of S_1 and S_2 layers can be expected to influence strongly the longitudinal shrinkage (Cave 1972). The helical cavities or checks penetrating deeply into S_2 are a very characteristic feature of compression wood (Timell 1986). The cellular surface structure of tracheids should be as perfectly intact as possible to attain a strong glueline between fibers (Maloney 1977). In a previous study, glucan in S_2 layer was also responsible for the high longitudinal shrinkage of compression wood was reported (Wloch 1975). Preston (1968) reported that high lignin content and peculiar distribution of lignin, the relatively low crystallinity of the cellulose were responsible for large longitudinal shrinkage of compression wood.

As known, cell wall thickness is directly related to the density of wood. If cell walls are thin, the fiber may collapse, and this in combination with greater flexibility of the thin-walled fiber will lead to more intimate contacts between adjacent fibers and therefore better interfiber bonding. This will be reflected in higher internal bond strength between fibers (Suchsland and Woodson 1991). If cell walls are thick as well compression wood, cells may not collapse, and reduced fiber flexibility will lower internal bond strength in MDF panel. This results in weaker moisture resistance and higher thickness swelling ratio in the MDF panel made from furnish containing compression wood when the panel is exposed to high relative humidity.

In manufacture of MDF, panel density is determined by the degree of compaction of the mat in the hot press. High density wood will generally result in higher bulk density of the fiber furnish and the mat and, at a given panel density, lower compression ratio (ratio of panel density to wood density). High compression ratios obtained with low wood density promote more intimate contact between fibers. Compression wood density is higher than normal wood density of the same species; its density is commonly 10–20% and sometimes as much as 40% higher (Haygreen and Bowyer 1996). The thick cell walls and wide latewood contribute to specific gravity much higher than that of normal wood tracheids. For this reason, compaction ratio of the MDF panels made from furnish containing larger compression wood is lower than that of the MDF panels made from furnish containing lower compression wood. The higher thickness swelling values of type A panels were attributed to lower compression ratio during hot pressing of the mat and weaker internal bond between the fibers than type B panels. Although type A panels had higher air-dry density (0.81 g/cm³) than that (0.79 g/cm³) of type B panels, dimensional stability of type A panels were inferior to that of type B panels.

4 Conclusion

The results revealed that MDF could be manufactured from the pine fiber furnish containing 75% of compression wood but dimensional stability of the panels was poor compared to the panels the fiber furnish containing 10% of compression wood. It is concluded that pine compression wood fibers influence the dimensional stability of panels because of their anatomical, chemical, and mechanical properties. Consequently, based on the findings obtained from this study, proportion of compression wood in the panel manufacturing should be reduced as far as possible to eliminate its negative effect on the dimensional stability of the panel.

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