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# Effect of panel density on dimensional stability of medium and high density fiberboards

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**Abstract** This study investigated the relationship between panel density and dimensional stability properties of commercial manufactured medium and high density fiberboards (MDF and HDF, respectively). Experiments were conducted using DIN EN 318 (2005) standard method to determine expansion and swelling properties of the MDF and HDF as a function of panel density. A significant relationship was found between panel density and dimensional stability of the panels. Our results showed that dimensional stability of MDF and HDF panels were adversely affected by panel density. The linear expansion/contraction and thickness swelling/shrinkage increased with increasing panel density, principally for densities above 850 kg/m$^3$. The thickness swelling and shrinkage values were higher than linear expansion and contraction values.

## Introduction

Medium and high density fiberboards (MDF and HDF) are wood-based composites formed by break down softwood and hardwood into wood fibers, in a defibrator, combining it with wax and resin, and forming panels by applying high-temperature and pressure in a hot press. MDF typically has a density of 600–800 kg/m$^3$, while HDF has a density of 800–1,100 kg/m$^3$. MDF is one of the most rapidly growing composite panel product in the market. The Europe's annual MDF production capacity is forecast to reach 14.03 million m$^3$ by the end of 2007 [1]. Smooth and solid edges of MDF can be easily machined and finished, and the uniform surface provides an excellent substrate for painting or applying decorative overlays. The homogenous edge of MDF allows intricate and precise machining and finishing techniques. It is an excellent substitute for solid wood in many interior and exterior applications such as toys and games, furniture and cabinets, molding, window and door frames, wall paneling, siding and roof sheathing.

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. Because dimensional stability of wood-based composites is critical in most applications, the maximum allowable dimensional change in such products is limited by standards [2]. Linear expansion or contraction, in occurring response to increased or decreased moisture content of the material, is one of the most important properties of the fiberboards. 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 [3]. Expansion and contraction values of fiberboard, thus, become important design parameters.

It is known that moisture content and panel density affect dimensional stability of the wood-based composites. Consequently, when moisture content is unevenly distributed through fiberboard thickness, panel thickness swelling and linear expansion vary accordingly. The moisture content profile corresponds to the characteristic vertical

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distribution of density (density profile) and it affects also the distribution of thickness swell [4]. For this reason, a key product attribute of MDF is the density profile through the panel thickness. The density profile describes the change in panel density through the panel thickness and usually reflects a high surface density and a lower core density [5]. The surface layers in MDF and HDF, although thinner as seen in Fig. 1, due to their higher compaction ratio, account for a more important portion of the overall thickness swell as compared to the core layer. The typical density profile of MDF presents higher density zones close to panel surfaces and lower density zones in the core of the panel. Although the boundaries between these zones are not precisely defined, with approximation they can be considered as separate layers (Fig. 1) [4]. A superior MDF panel laminating, gluing and finishing should have a deep density profile, in which the face density is considerably higher than the core density [5].

Expansion properties (linear expansion and contraction) and swelling properties (thickness swelling and shrinkage) were key parameters in the dimensional stability of wood composites. Linear expansion values are considerably smaller than thickness swelling value. Particularly, linear expansion is considered as the control factor in qualifying the behavior of wood-based composites exposed to moisture [6]. 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 [7].

Although research has been conducted to improve the dimensional stability of wood-based composites, the results have often been contradictory. It was found that panel density had not an effect on linear expansion of particleboard in some previous studies [8–10]. Most other researchers observed that when density increases, the expansion properties of wood composites also increase [2, 11–14]. For MDF and HDF, there is limited literature data available for the effects of the panel density on the linear expansion and thickness swelling at exposure to water in vapor phase. Because of these contradictory

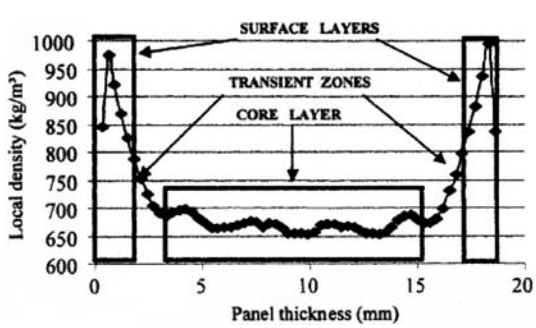


**Fig. 1** Actual vertical density profile in MDF [4]

results, the objectives of this study were (1) to determine expansion and swelling properties of MDF and HDF panels as a function of panel density; and (2) to determine if a significant relationship between panel density and its dimensional stability occurred.

## Materials and methods

### MDF and HDF panels preparation

Commercial MDF and HDF panels with dimensions of 2,800 mm by 2,100 mm by 11 mm were manufactured with urea–formaldehyde resin at a content of 10% (based on the oven-dry weight of the fibers) at SFC Integrated Wood Company located in Kastamonu, Turkey. The panels were made from a mix of hardwood (beech) and softwood (pine) fibers by the dry process. MDF panels presented target densities of 720, 760, and 800 $kg/m^3$ while HDF panels had target densities of 850 and 1,000 $kg/m^3$, respectively. A total of 15 panels, 3 repetitions for each panel density, were tested.

### Vertical density profile measurement

Five specimens (50 mm × 50 mm) from each panel density level were used to determine the vertical density profiles of the panels. The vertical density profile were measured using a commercial density profiler (GreCon® density analyzer DA-X) based on X-ray scanning system. The density profile reflects density change through the panel thickness. For an efficient and faultless entry of the sample data, an electronic measuring caliper was used to measure the sample dimensions (thickness, length, width). The caliper was equipped with a serial interface and automatically transmits the measured data to the visualization computer. Depending on the density profile of the material, more or less X-radiation penetrates the samples. This radiation was measured and evaluated by the transducer and transferred to the visualization computer. Figure 2 shows a typical density profile of panels with panel density of 760 $kg/m^3$.

### Determination of dimensional stability

The linear and thickness variations of the panels were determined in conformance with DIN EN 318 standard [15]. 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 at 20 ± 2 °C. The linear or thickness variations induced by a change in

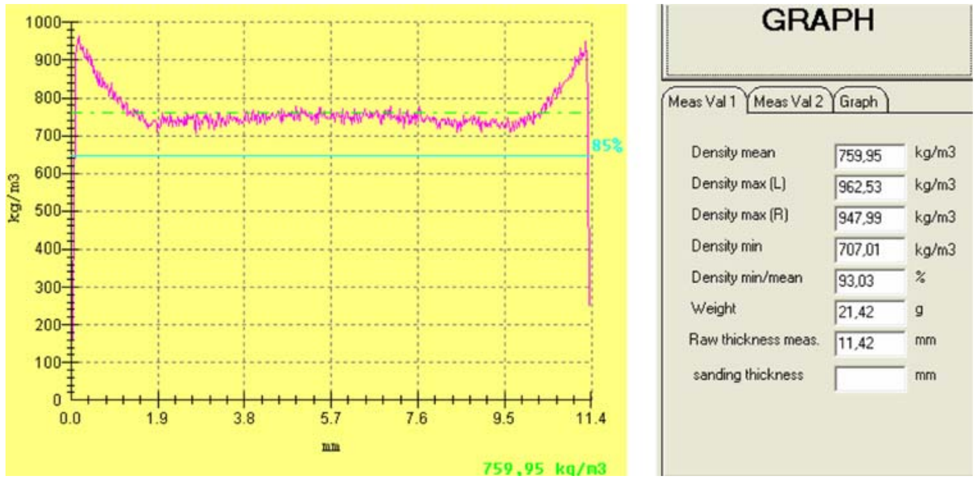


**Fig. 2** Typical vertical density profile of MDF with panel density of 760 kg/m$^3$

moisture, also called thickness swelling or shrinkage for thickness variation and linear expansion or contraction for linear variation. The increases in length and thickness were monitored from 65 to 85% relative humidity in adsorption as defined in Table 1 (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 1.

A total of 40 specimens with dimensions of 300 mm by 50 mm by 11 mm, 20 parallel and 20 perpendicular to the sanding direction of the panels, were tested for each panel density level to determine linear and thickness variations. Linear and thickness variations of the specimens 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: 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 1). The specimens were conditioned until constant weight and moisture content in a climate chamber for each treatment level. For this aim, 10 specimens parallel to the sanding direction of the panel were used for regime 1 and 10 for regime 2. The same procedure was applied to specimens perpendicular to the sanding direction of the panel.

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. 3 with an accuracy of ±0.01 mm using equipment according to the DIN EN 318 standard (Fig. 4). The linear expansion and contraction were calculated as follows:

$$LE_{65to85} = (L_{85\_final} - L_{65\_initial}) \times 100/L_{65\_initial} \quad \text{(with using of regime 1 results)} \tag{1}$$

$$LC_{65to30} = (L_{65\_initial} - L_{30\_final}) \times 100/L_{65\_initial} \quad \text{(with using of regime 2 results)} \tag{2}$$

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

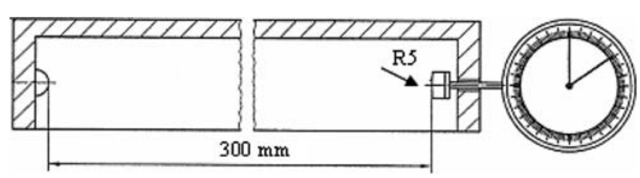


**Fig. 3** Test apparatus used for measuring of expansion and contraction of the specimens. About 300 mm means specimen length. R5 means that radius is 5 mm (From EN 318)

**Table 1** Two conditioning regimes of the specimens at consecutive relative humidities

| 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 |

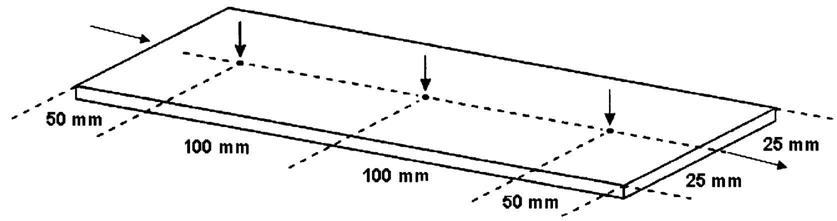


**Fig. 4** Positions for thickness and length variations measurements

conditioned at 85% RH (mm); $L_{65\_initial}$: initial length of the specimen conditioned at 65% RH (mm); $LC_{65\ to\ 30}$: linear contraction after RH change from 65 to 30%, based on the length measured at 65% RH (%); $L_{30\_final}$: final length of the specimen conditioned at 30% RH (mm).

Determination of thickness swelling and shrinkage

The thicknesses were taken at three points at the specimens medium width with an accuracy of ±0.01 mm (Fig. 4). Thickness swelling and shrinkage properties were calculated as follows:

$$TS_{65to85} = (T_{85\_final} - T_{65\_initial}) \times 100/T_{65\_initial} \quad \text{(with using of regime 1 results)} \tag{3}$$

$$TSh_{65to30} = (T_{65\_initial} - T_{30\_final}) \times 100/T_{65\_initial} \quad \text{(with using of regime 2 results)} \tag{4}$$

where $TS_{65\ to\ 85}$: 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); $TSh_{65\ to\ 30}$: thickness shrinkage after RH change from 65 to 30%, based on the thickness measured at 65% RH (%); $T_{30\_final}$: final thickness of the specimen conditioned at 65% RH (mm).

An analysis of variance (ANOVA) was performed on the linear and thickness variations data to evaluate differences between panel densities at 0.01 probability level. Significant differences among mean values of the specimens as a function of the panel density were determined by the Duncan's multiple range test.

## Results and discussion

Table 2 shows results of linear expansion/contraction and thickness swelling/shrinkage of the experimental panels. Statistical analysis revealed significant differences between linear and thickness variation values obtained in adsorption at 65–85% RH and desorption at 65–30% RH at a 0.01 probability level. Figures 5 and 6 present the linear expansion/thickness swelling and linear contraction/thickness shrinkage, respectively, in adsorption and desorption conditions as a function of panel density.

The linear expansion/contraction and thickness swelling/shrinkage increased with increasing panel density, especially in densities above 850 kg/m$^3$ (HDF panels) as shown in Table 2. Linear regression analysis for expansion and swelling changes of the panels revealed a significant correlation between dimensional stability and panel density. It was found a strong correlation with $R^2$ = 0.93 and $R^2$ = 0.89 values between linear expansion to the parallel and perpendicular to the sanding direction of the panel as a function of the panel density, respectively (Fig. 5). A similar correlation with $R^2$ = 0.83 and $R^2$ = 0.79 values was found between thickness swelling in two principal directions of the panel and the density. It was observed that the increased panel density adversely affected linear expansion and thickness swelling of the specimens. Similar results were found in a previous study [13]. Under conditions of 40 °C and 90% RH, linear expansion of particleboard increased with increasing of panel density. In general, linear and thickness variations in parallel and perpendicular to the sanding direction of the panel were not statistically significant. ANSI A.208.2-2002 standard [16] was used here for comparison of linear expansion property since there was no established maximum performance requirement for MDF and HDF in European standards. According to ANSI A.208.2-2002 standard, linear expansion of fiberboards performed between 50 and 80% RH must have maximum values of 0.30% [14]. Linear expansion except for the perpendicular to the sanding direction with panel density of 1,000 kg/m$^3$ did not exceed the maximum values required by the ANSI A.208.2-2002 standard.

The linear expansion and thickness swelling values obtained in adsorption conditions were higher than those obtained in desorption conditions at the same relative humidity level (Table 2). For example, average linear expansion value parallel to the sanding direction of the panels with panel density of 1,000 kg/m$^3$ was 0.30% in relative humidity change from 65 to 85% (adsorption) while average linear contraction for the same panel density was 0.22% in relative humidity change from 65 to 30%

**Table 2** Linear expansion/contraction and thickness swelling/shrinkage properties in two principal directions and vertical density profiles of MDF and HDF panels

| | Average panel density ($kg/m^3$) | Dimensional stability | | | | | | | | Vertical density profile | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Parallel to the sanding direction of the panel | | | | Perpendicular to the sanding direction of the panel | | | | | | |
| | | $LE_{65\ to\ 85}$ (%) | $LC_{65\ to\ 30}$ (%) | $TS_{65\ to\ 85}$ (%) | $TSh_{65\ to\ 30}$ (%) | $LE_{65\ to\ 85}$ (%) | $LC_{65\ to\ 30}$ (%) | $TS_{65\ to\ 85}$ (%) | $TSh_{65\ to\ 30}$ (%) | Top surface ($kg/m^3$) | Core ($kg/m^3$) | Bottom surface ($kg/m^3$) |
| MDF | 720 | 0.14 A (7.6) | 0.11 A (9.5) | 2.80 A (10.1) | 2.05 A (0.1) | 0.14 A (7.3) | 0.11 A (7.3) | 2.85 A (8.7) | 2.14 A (7.8) | 901.3 (8.9) | 656.6 (6.5) | 912.8 (10.3) |
| | 760 | 0.16 AB (8.4) | 0.13 AB (6.6) | 3.11 AB (7.9) | 2.31 AB (8.5) | 0.16 AB (5.8) | 0.13 AB (3.9) | 3.14 AB (4.4) | 2.40 AB (8.4) | 943.9 (7.4) | 707.4 (5.8) | 948.5 (9.5) |
| | 800 | 0.18 B (6.0) | 0.15 B (6.0) | 3.40 B (10.8) | 2.60 B (8.8) | 0.18 B (9.5) | 0.13 B (5.2) | 3.45 B (3.5) | 2.71 B (9.4) | 954.1 (10.5) | 753.2 (8.6) | 959.0 (11.3) |
| HDF | 850 | 0.25 C (9.6) | 0.19 C (6.8) | 4.83 C (5.6) | 3.74 C (7.1) | 0.26 C (8.8) | 0.20 C (8.5) | 4.88 C (7.9) | 3.44 C (5.6) | 965.6 (4.7) | 794.1 (6.4) | 970.7 (8.3) |
| | 1,000 | 0.30 D (6.5) | 0.22 D (3.4) | 5.11 C (4.8) | 4.24 D (5.1) | 0.31 D (3.8) | 0.27 D (6.7) | 5.01 C (5.0) | 4.12 D (6.3) | 1,064.3 (9.7) | 941.7 (6.6) | 1,058.2 (5.4) |

Numbers in parentheses are standard deviations. LE, Linear expansion; LC, Linear contraction; TS, thickness swelling; TSh, thickness shrinkage

Homogeneity groups: means with the same letter are not significantly different at a probability level of 0.01 according to the Duncan's multiple range tests

(desorption). As for thickness swell and shrinkage values, average thickness swelling value (5.11%) parallel to the sanding direction of the panels with panel density of 1,000 $kg/m^3$ was higher than average thickness shrinkage value (4.24%) for the same panel density. In wood and wood-based 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) [4].

The thickness swelling and shrinkage values were much higher than the values of linear expansion and contraction values. In desorption, the specimens with panel density of 720 $kg/m^3$ had the lowest linear contraction with 0.11% and thickness shrinkage with 2.05% while the highest linear contraction with 0.27% and thickness shrinkage with 4.24% were found for the specimens with panel density of 1,000 $kg/m^3$. As for in adsorption, the specimens with panel density of 720 $kg/m^3$ had the lowest linear expansion (0.14%) and thickness swell (2.80%) while the highest linear expansion (0.31%) and thickness swell (5.11%) were found for the specimens with panel density of 1,000 $kg/m^3$. These results are in agreement with the results obtained in previous studies [2, 12]. It was determined a significant correlation with $R^2$ = 0.90 and $R^2$ = 0.96 values between linear contraction to the parallel and perpendicular to the sanding direction of the panel and the panel density, respectively (Fig. 6). As for thickness shrinkage, it was found a correlation with $R^2$ = 0.89 and $R^2$ = 0.95 for parallel and perpendicular to the sanding direction of panel as a function of panel density, respectively. Based on the linear regression analysis results, it can be concluded that there was a strong relationship between dimensional stability and panel density in both adsorption and desorption conditions.

Thickness swelling and linear expansion in two principle directions of the specimens with panel density of 720 and 760 $kg/m^3$ were not significant different between themselves. However, when the panel density exceeded 850 $kg/m^3$ (HDF panels), linear expansion and thickness swelling values in the parallel and perpendicular directions of the specimens were significantly increased according to Duncan's multiple range test (Table 2). Generally, high density fiberboards present higher compression than lower density ones. In the high density fiberboards, the higher compaction ratio implies that more compressive deformation has been imparted onto the fibers during hot pressing and the fibers were under greater compressive set [17]. The increase in thickness swelling occured in the higher panel densities can be attributed mainly to the release of compression, as well as the deterioration of the inter-particle bonding, which is overcomed by the spring-back effect and hence eventually fails to hold the fibers together.

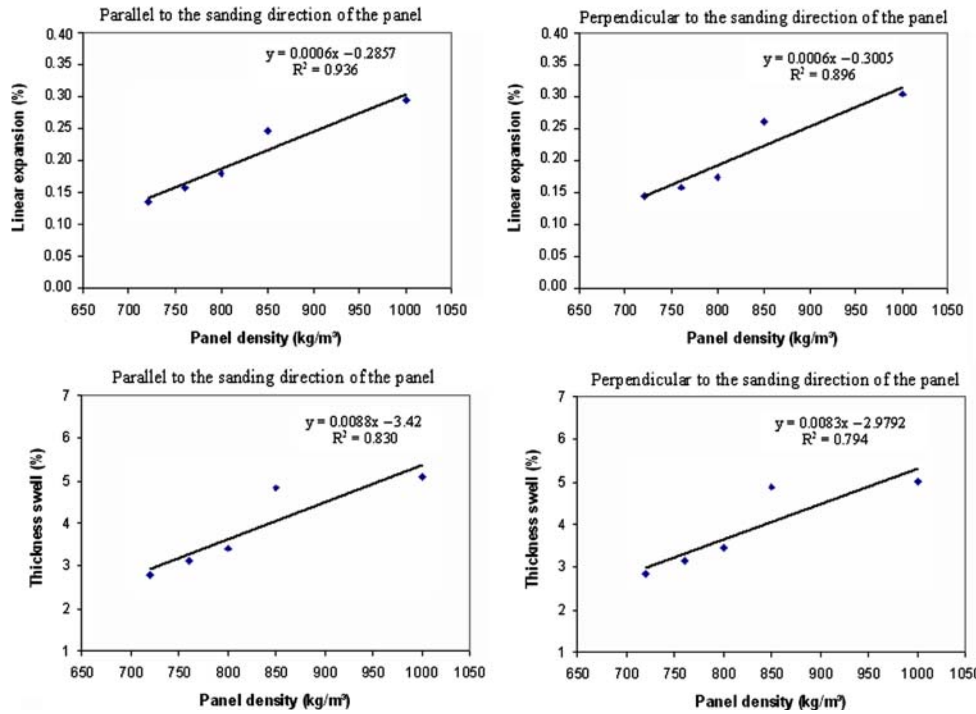


**Fig. 5** Relationship between panel density and linear expansion and thickness swelling values in adsorption conditions

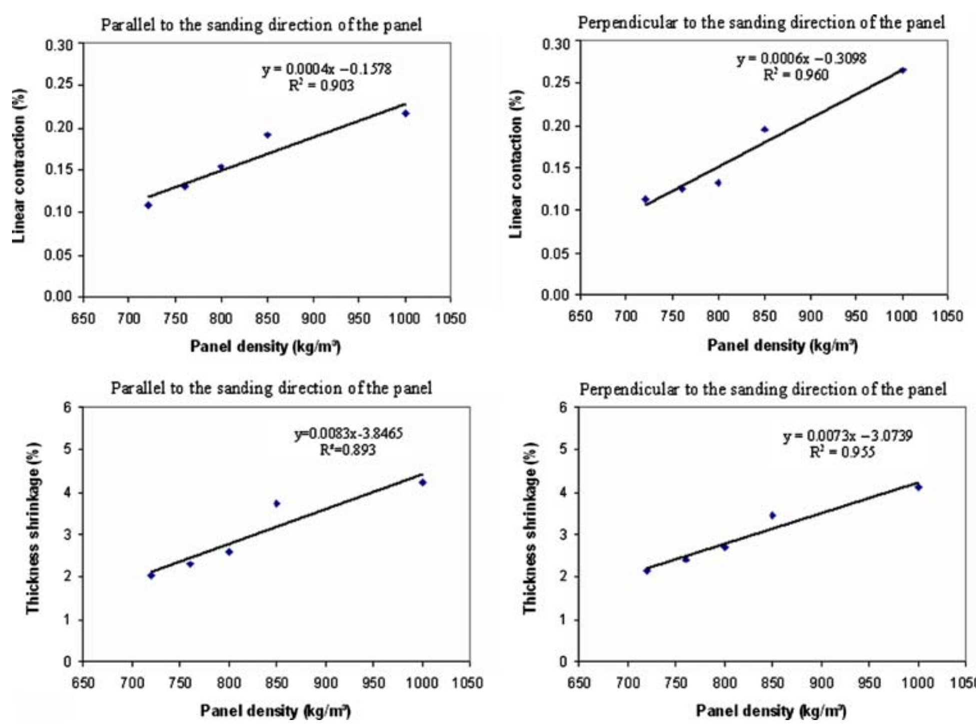


**Fig. 6** Relationship between panel density and linear contraction and thickness shrinkage values in desorption conditions

Furthermore, the peculiar behavior of linear expansion as a function of panel density may be explained at the cellular level. In fiberboards, similarly to solid wood, the linear expansion is caused by swelling of the wood cell walls. Under pressure and heat as used in hot pressing, cell lumina and/or vessels in hardwoods collapse, and fractures in walls of wood cell develops [18]. As a result of mat densification, the amount of wood material in the panel increases. This phenomenal is more intense with increased panel density resulting in increased thickness swelling and linear expansion after moisture absorption [19]. As known, the mat pressure in high density fiberboard is higher than that of low density fiberboards. The increased panel density depend on pressure level will increase wood substance, especially amount of $S_1$ and $S_2$ layers in walls of wood cell, per unit volume and responsible for the hygroscopic swelling and shrinkage in the panel. $S_1$ and $S_2$ layers represent the swelling and shrinkage potentials of wood fibers in the panel [20]. In addition, the mat densification during hot pressing causes another swelling component, partially permanent, called spring-back-swelling forces responsible for partial failures of bonds between fibers, which in turn create additional void spaces.

Layer thickness swell of fiberboards after water exposure is significantly and positively related to layer density. The correlation coefficient between the actual layer thickness and layer density increases as water exposure prolonged. Two shoulders on the density profile resulted in two shoulders on the thickness swell profile after water exposure. For this reason, the top side of the panels swells significantly more than the bottom. MDF panels during early water exposure exhibit a vertical moisture distribution, that in turn result in high face thickness swell and low core thickness swell [21]. This effect might be related to the higher plastification of the particles in the surface layers due to long lasting high temperatures [22]. The greater thickness swell and linear expansion in the high panel densities (HDF panels) tested in this study were attributed to higher densities of their surface and core layers as compared to low panel densities (MDF panels) (Table 2). The greater thickness swell in the surface layers of MDF and HDF panels suggests that efforts to improve dimensional stability of the panels should be focused on stabilizing the high density surface layers. For example, more adhesive/wax or improved adhesive/wax systems could be applied to the surface fibers to improve the dimensional stability of the whole panel [23]. Besides, fibers treated with heat (150–180 °C and 30–60 min) or maleated polypropylene wax composed of 99% polypropylene and 1% maleic anhydride wax can reduce the hygroscopic characteristics of MDF panels without significantly reducing the mechanical properties or changing the vertical density profile of the panels [24, 25]. Interactive restraint between the two faces and the core of the wood-based composites was sensitive to changes in humidity [12]. Based on the findings obtained in this study, it is thought that an increase in surface and core layer densities across the panel thickness increases interactive restraint between surface and core layers.

## Conclusions

When wood-based composites are exposed to humid conditions, dimensional changes take place. The results obtained in this study showed that the dimensional stability of MDF and HDF panels were adversely affected by panel density. The linear expansion/contraction and thickness swelling/shrinkage increased with increasing panel density, principally in densities above 850 $kg/m^3$. The thickness swelling and shrinkage values were higher than linear expansion and contraction values. Thickness and linear variations in conditions of increasing or decreasing moisture content were positively correlated to density. Thickness swelling and linear expansion of MDF and HDF panels were attributed to the release of the compressive stresses, hygroscopic swelling of wood fibers, and the deterioration of the inter-particle bonding. It is thought that the density distribution across the panel thickness affects the thickness swell and linear expansion of the panel.

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