

The effect of cyclic relative humidity exposure, sanding and grooving on the dimensional stability of solid wood parquet

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Abstract

In this study, the effect of cyclic relative humidity changes, sanding and grooving on the dimensional stability of solid wood parquet were evaluated. The experiments were carried out on oak (*Quercus petraea*) and sapele (*Entandrophragma cylindricum*) wood species. Firstly some physical tests (density, shrinkage, and swelling) were carried out on 20×20×30 mm specimens obtained from these two species. After the physical tests the parquet size specimen groups were obtained both in radial and tangential section directions and in two sizes; narrow (250×50×15 mm) and wide (250×90×15 mm). One group of parquet size specimens was sanded and the other group was grooved. There was also a group of specimen for control.

After being conditioned to equilibrium moisture content at 65% relative humidity, specimens were placed in a climate chamber and exposed to cyclic relative humidity changes. The dimensions of the specimens were measured between different environmental conditions and the dimensional change was evaluated by taking into consideration the mentioned physical properties. The results show that cyclic relative humidity changes mainly resulted with an increase in the dimensional stability of sanded and cyclic conditioned specimens. There was not a significant change in the dimensional stability of grooved specimens.

Keywords

Solid wood parquet, Dimensional stability, Sanding, Grooving, Cyclic conditioning.



1. Introduction

Wood is an important organic material which is commonly used in the construction industry. It is mechanically strong, light in weight, resistant to various factors and it is visually attractive (Bekhta & Niemz, 2003; Juodeikienė, 2013). Wood is also a renewable and an environment-friendly material (Chotikhun & Hiziroğlu, 2016). It can be used safely as a structural material, but it is more commonly used as a finishing (floor, wall, ceiling claddings), mostly as a flooring material (Hyttinen et al., 2010). The most important reasons for preference of wood are; its visual properties and warm surface temperature. However, flooring materials should also have some other specific properties such as; high compressive strength, dimensional stability, heat and noise control, abrasion resistance and adhesion capacity. When wood is evaluated according to these properties, it can be stated that it has a higher performance than most of the other building materials. Thus, wood is used as a flooring material for centuries (Németh et al., 2014; Toydemir et al., 2000).

Despite many advantages, wood can easily be affected by the changes of moisture content. The porous structure of wood desorbs and absorbs water/water vapor to its cells and as a result the wood shrinks and swells (FPL, 1957; Juodeikienė, 2013; Tomak et al., 2014). This behavior is called “wood movement” which plays an important role in the physical deterioration and shortens the service life of the material.

In general wood’s movement is affected by; moisture content, density, content of extractives, mechanical stress and abnormalities in wood’s structure. Among these factors, moisture content is the most important one because the others are reasoning from wood’s structure but moisture content depends on the relative humidity of the surrounding air and cannot be controlled easily (Tsoumis, 1991).

The indoor air of a building is comprised of temperature, relative humidity, air, and heat movement. The balance of these constituents is effected by the materials and equipment used in construction. When they are evaluated;

humidity is said to be the most important. Humidity fluctuations decreases the indoor air quality, cause formation of biological agents and cause shrinkage and swelling on building materials. Wood is one of the most affected building material from dimensional changes because of its natural origin (Wang & Tsai, 1998). Therefore the relative humidity changes in buildings has to be kept in a safe range (Melin & Bjurman, 2017). Also the shrinkage and swelling mechanism of wood has to be analyzed.

Water vapor is taken to the structure of wood by the hydroxyl groups which is located on the cell wall and have a hydrophilic behavior. Therefore the interventions related to the dimensional stability of wood usually depends on creating a blockage between the hydroxyl groups and water vapor to prevent absorption. The main dimensional stabilization techniques include; surface hydrophobization, impregnation, chemical modification and heat treatment (Kocaeft et al., 1991). Varnishing is used as a surface protection layer for parquets. The surface of solid wood parquet is varnished periodically. This layer prevents the absorption of water vapor and increase the dimensional stability to a certain extent. However because it is a very thin layer, varnish cannot prevent the movement of wood at humidity fluctuations.

Although the majority of dimensional stabilization interventions are dealing with surface treatment, there are some other physical applications which is said to be effective in improving dimensional stability; such as grooving, sanding and hygroscopic ageing. Flooring materials are manufactured with grooves at the back. Grooving the back of flooring materials shows which side is down, creates air movement, increases the adhesion surface and let the material lay flatter. Grooves are also said to increase the dimensional stability, reduce the weight and decrease transportation costs (Deteix et al., 2012). Sanding is applied to flooring materials in order to remove layer of dirt and ensure flatness of the surface (Rózańska, 2013). But because it decreases the thickness of the materi-

Table 1. Groups and numbers of the specimens.

Groups of specimens	OAK (<i>Quercus petraea</i>)				SAPELE (<i>Entandrophragma cylindricum</i>)			
	Radial		Tangential		Radial		Tangential	
	Narrow	Wide	Narrow	Wide	Narrow	Wide	Narrow	Wide
	1. Group	2. Group	3. Group	4. Group	5. Group	6. Group	7. Group	8. Group
No Groove (G_0)	20	20	20	20	20	20	20	20
Few Grooves (G_1)	20	20	20	20	20	20	20	20
Lot of grooves (G_2)	20	20	20	20	20	20	20	20
Sanding (S)	25	25	25	25	25	25	25	25
TOTAL	85	85	85	85	85	85	85	85

al and the movement of wood is directly proportional with the dimensions of the material it can also be mentioned that it increases the dimensional stability. In addition, the ambient humidity changes cause a reduction in the movements of wood, which can be described as the hygroscopic ageing of wood (Esteban et al, 2005).

The main aim of the study is to determine the effect of grooving, sanding and cyclic relative humidity changes on the dimensional stability of oak and sapele specimens. It was also aimed to determine and compare the behavior of narrow and wide specimens prepared in tangential and radial section directions.

2. Materials and methods

2.1. Materials

Solid wood parquet specimens were obtained according to TS 2039 (1988) standard and the same lumber group was used during the production stage in order to prevent different qualities between specimens. Oak (*Quercus petraea*) and sapele (*Entandrophragma cylindricum*) were used in the manufacture of the specimens. 680 specimens were cut from oak and sapele wood. There were two reasons behind

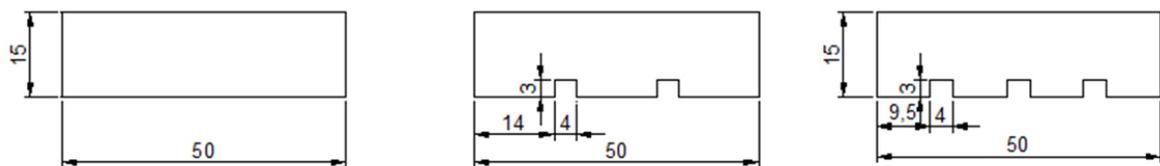
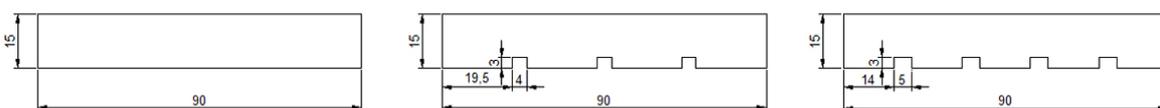
the selection of these species; first their relatively more frequent use in the parquet industry and second making a comparison between the imported and local species.

50 specimens of each wood species were used at physical tests which have 20×20×30 mm dimension. Parquet size specimens had different dimensions. Oak and sapele specimens were mainly cut in radial and tangential sections. All radial and tangential oak and sapele specimens also had narrow and wide dimensions. Narrow specimens had a dimension of 250×50×15 mm and wide specimens had a dimension of 250×90×15 mm. Table 1 shows the groups and numbers of the specimens.

The sizes and the type of grooves is shown in Figure 1 and 2.

2.2. Methods

Physical tests were carried out to ensure the regularity of the specimens and to determine defects that might escape from visual inspection. Determination of density (TS 2472, 1976), radial and tangential swelling (TS 4084, 1983), radial and tangential shrinkage (TS 4083, 1983) tests were carried out on 20×20×30 mm specimens at this phase.

**Figure 1.** Narrow G_0 (also S), G_1 and G_2 specimens.**Figure 2.** Wide G_0 (also S), G_1 and G_2 specimens.

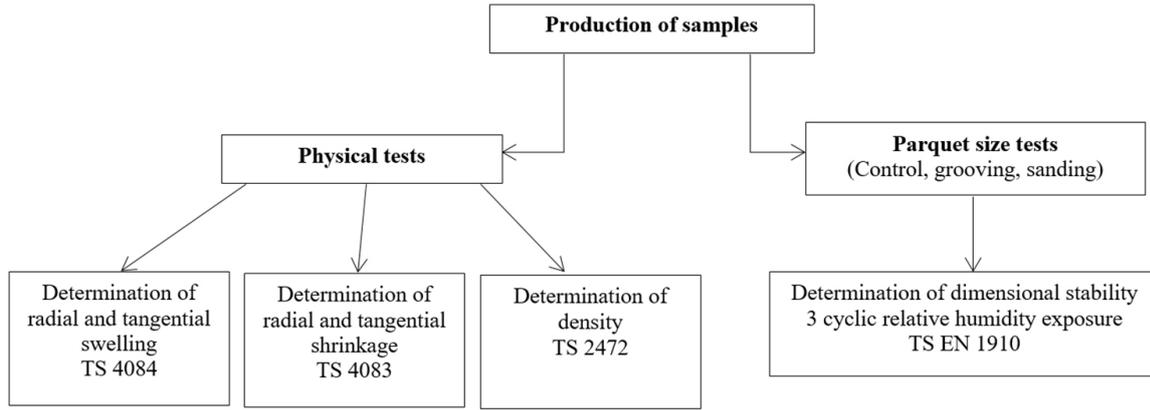


Figure 3. Flow diagram of the experimental stage.

Cyclic relative humidity exposure tests were carried out on parquet size specimens at humid and dry environmental conditions. After every cyclic exposure, the dimensions of the specimens were measured again in order to determine the dimensional change of specimens. Figure 3 illustrates the steps of the experimental stage.

Before the experimental campaign the specimens were conditioned in a room with a relative humidity of 65% and a temperature of 20°C (standard atmosphere) until they reach the equilibrium moisture content (12%).

2.2.1. Physical tests

Determination of density test was carried out according to TS 2472. Specimens were conditioned in a room with a relative humidity of 65% and a temperature of 20°C until the dimensional variation was smaller than 0.5%. The average density of the specimens was determined for a moisture content of 12% with the Formula 1;

$$\rho_{12\%} = m_{12\%} / V_{12\%} \text{ (g/cm}^3\text{)}$$

Here;

m: mass (g)

V: volume (cm³)

Dimensions of the specimens (Figure 4) were measured with a caliper and mass of the specimens was weighed with an electronic weighing machine.

The radial and tangential swelling tests were carried out according to TS 4084. After conditioning the specimens at standard atmosphere then the radial and tangential swelling specimen group were dried in the oven at 103±2°C. The radial and tangential dimensions were measured with a caliper as lr_{\min} and lt_{\min} after oven drying (0% moisture content).

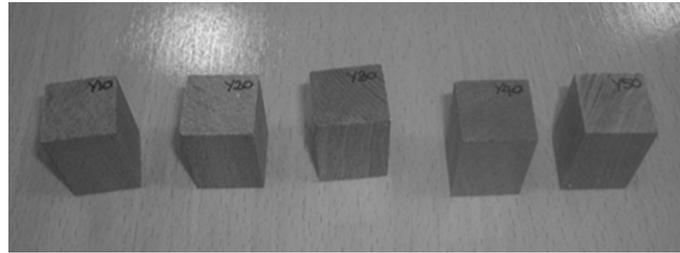


Figure 4. Specimens of physical tests.

After this period the specimens were kept in normal conditions for a while and submersed in distilled water at 5°C until saturation (fiber saturation point). Then their radial and tangential dimensions were measured again as lr_{\max} and lt_{\max} .

The linear swelling was determined with Formula 2;

$$\alpha_{max} = \frac{l_{max} - l_{min}}{l_{min}} \times 100 \text{ (\%)}$$

The radial and tangential shrinkage was measured according to TS 4083. After conditioning the specimens at standard atmosphere, the radial and tangential shrinkage specimen group was submersed in distilled water at 5°C until saturation (fiber saturation point). The radial and tangential dimensions were measured with a caliper as lr_{\max} and lt_{\max} after water soaking.

After this period the specimens were kept in normal conditions for a while and left in the oven at 103±2°C. The dimensions were measured as lr_{\min} and lt_{\min} after oven drying.

The linear shrinkage was determined with Formula 3;

$$\beta_{max} = \frac{l_{max} - l_{min}}{l_{max}} \times 100 \text{ (\%)}$$

Table 2. Results of preliminary tests.

Groups of specimens	OAK (<i>Quercus petraea</i>)		SAPELE (<i>Entandrophragma cylindricum</i>)	
	Radial	Tangential	Radial	Tangential
Shrinkage	4.43%	8.46%	5.65%	6.50%
Swelling	4.86%	10.88%	4.60%	7.40%
Density	0.74 g/cm ³		0.72 g/cm ³	

Table 3. A cycle of conditioning during the dimensional stability test.

Conditioning	Duration	Circumstances	Measurement
I. Humid environment	4 weeks	85% relative humidity, 20±2°C temperature	D _h
II. Dry environment	4 weeks	35% relative humidity, 20±2°C temperature	D _d

**Figure 5.** Climatic test chamber.

According to the results of physical tests; there are acceptable differences between literature and the test results (FPL, 1957). Therefore it can be stated that the specimens were obtained from regular planks and will not display an unusual behavior. The results of the physical tests are given in Table 2.

2.2.2. Parquet size tests

The main aim of the dimensional stability test is; comparing the dimensional change of the specimen between the initial standard climatic condition and another specified climatic condition. The test was carried out according to TS EN 1910 (2003) standard.

The specimens were firstly conditioned in standard atmosphere to reach equilibrium moisture content (65% relative humidity, 20°C temperature). Their dimensions were measured and then they were exposed to cyclic humid and dry environmental conditions in a climatic test chamber. Caliper was used for measuring the dimensions of

tangential and radial direction and meter was used for the longitudinal direction. The experiments were carried out with a Climatic Test Chamber (Figure 5) in which the relative humidity and temperature could be programmed.

The environmental conditions and the time of exposure is given in Table 3. After each conditioning the dimensions of the specimens were measured again.

After conditioning the specimens at equilibrium moisture content, the dimensions were measured as D_i.

At the first part of the cycle the specimens were conditioned in humid environment. After four weeks conditioning at a temperature of 20±2°C and 85% relative humidity the dimensions of the specimens were measured as D_h. The second part of the first cycle is conditioning the specimens in dry environment. After that the specimens were conditioned for four weeks at a temperature of 20±2°C and 35% relative humidity, then their dimensions were measured again as D_d. After the first cycle the dimensional change (*dcr*) of the specimens was determined in percentages with Formula 4;

$$dcr = \frac{(18/h) Dh - Dd}{Di} \times 100\%$$

Here;

dcr= the relative cumulative dimensional change as two digit fraction,

Di=dimension after normal conditioning,

Dd=dimension after dry conditioning,

Dh= dimension after humid conditioning and

h= 18 (according to TS EN 1910)

Table 4. The tangential dimensional changes (%) of the grooved specimens.

Specimen group		G ₀ (No groove)		G ₁ (Few grooves)		G ₂ (Lot of grooves)	
		mean	st. dv.	mean	st. dv.	mean	st. dv.
OAK	1. group	1.89%	0.27	1.78%	0.26	1.57%	0.25
	2. group	1.90%	0.26	1.96%	0.41	1.94%	0.29
	3. group	1.90%	0.13	1.88%	0.21	1.86%	0.14
	4. group	2.40%	0.36	2.32%	0.25	2.29%	0.31
SAPELE	5. group	1.78%	0.18	1.74%	0.23	1.72%	0.14
	6. group	1.83%	0.18%	1.99%	0.23	2.00%	0.19
	7. group	1.93%	0.16	1.91%	0.12	1.89%	0.17
	8. group	2.28%	0.28	2.18%	0.26	2.20%	0.22

Thereafter the sanding (S) and cyclic relative humidity specimens (G₀) were exposed to two more cycles, each cycle including a humid and dry environment period. Sanding specimens had 15 mm thickness at first conditioning, 12 mm at the second and 8 mm at the last conditioning. After every sanding process the specimens were conditioned and the dimensions were measured again in order to determine the effect of sanding on the dimensional stability of parquet. Wide G₀ specimens were also conditioned three times in order to determine the effect of cyclic conditioning. G₁ and G₂ specimens were conditioned only once, to determine the effect of grooves on dimensional stability.

On the basis of test results, the values were statistically analyzed by means of analysis of variance test (ANOVA) using SPSS program (IBM, New York, USA). When ANOVA test result indicated a significant difference among factors, a comparison of the means was made by using Duncan's multiple range test.

3. Results and discussion

Test results were evaluated to determine the effect of grooves, sanding and cyclic relative humidity changes on the dimensional stability of solid wood parquets.

3.1. Effect of grooves on dimensional stability

The radial and tangential dimensional changes of the grooved specimens as percentage were obtained (Table 4) after a cycle comprised of a

humid and dry relative humidity exposure. The dimensional changes were measured on the tangential, radial and longitudinal axis. Since longitudinal shrinkage and swelling of wood is negligible, as stated in the study of Constant et al. (2003), the results of dimensional change on longitudinal axis were not evaluated.

In Table 4, 1. – 4. groups are oak specimens and 5 – 8 groups are sapele specimens as mentioned before in Table 1. According to the test results; the dimensions of the specimens mostly increased with increasing relative humidity values and decreased with decreasing relative humidity values.

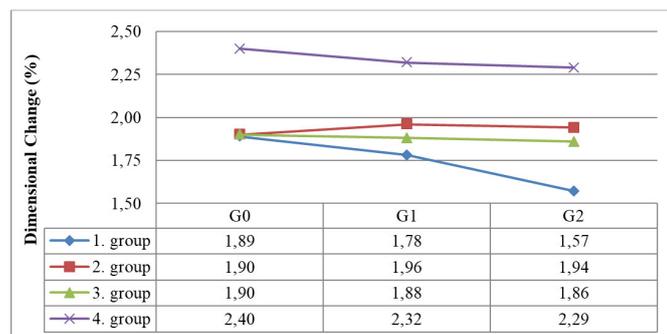
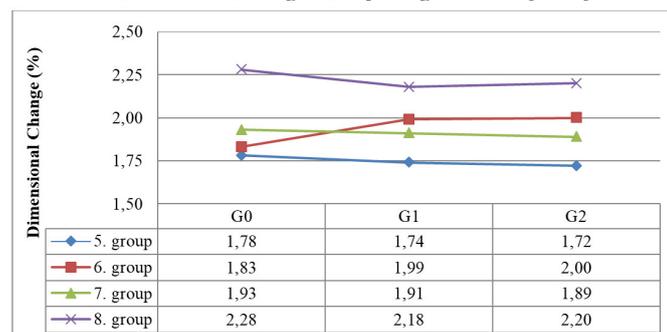
Table 5. Dimensional change (%) of the grooved oak specimens.**Table 6.** Dimensional change (%) of the grooved sapele specimens.

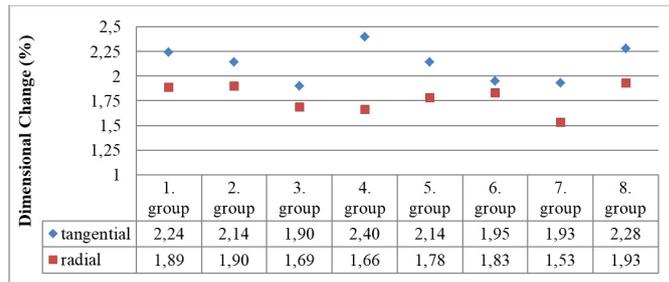
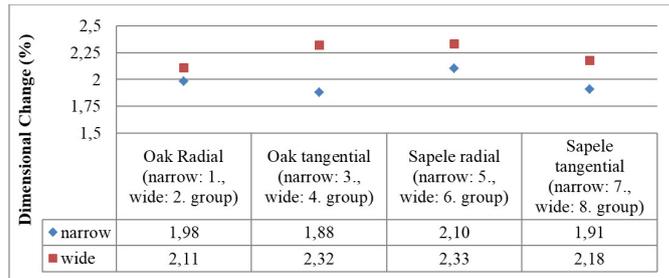
Table 7. The dimensional change percentages of specimen groups.**Table 8.** The dimensional change percentages of narrow and wide G_1 specimen groups.

Table 5 and 6 presents the results of dimensional changes of the grooved oak and sapele specimens. It was observed that, the increase in groove amount adversely affected the dimensional change at most of the specimen groups. The dimensional change decreased with the increasing grooves as can be seen in 1, 3, 4, 5, and 7. specimen groups.

A one-way analysis of variance (ANOVA) test was carried out at a 5% significance level in order to evaluate the relationship between grooves and wood's movement. According to ANOVA results, it is revealed that there is not a significant relationship between dimensional stability and grooves.

The results also revealed that; the dimensional change of tangential specimens are higher than the radial specimens, as underlined in the study of

Booker et al. (1992). The tangential and radial dimensional change percentages of specimen groups are presented in Table 7 and the tangential dimensional change is higher than the radial dimensional change in all groups.

According to the results of the tests, the dimensional movement of wide specimens are also higher than the dimensional movement of narrow specimens in all of the specimen groups as can be seen in Table 8.

3.2. Effect of sanding on dimensional stability

The specimens were sanded two times. At the first cycle they had 15 mm thickness, after the first sanding process their thickness decreased to 12 mm and after the second sanding they were 8 mm. The dimensional changes (%) after each sanding and cyclic relative humidity exposure were given in Table 9.

According to the test results, it can be mentioned that dimensional stability of the specimens is improved after each sanding application. The most significant increase in dimensional stability is obtained after the first sanding. The dimensional movement percentage of all of the oak and sapele specimen groups has decreased as can be seen in Table 10 and 11.

According to the results of Duncan's test, S1 and S2 specimens have lower dimensional movement percentages than S0 specimens of both oak and sapele groups. This finding is relevant to the hysteresis behavior of wood. Hysteresis is a complicated phenomenon of wood which basically means that wood's equilibrium moisture content is different in desorption

Table 9. The dimensional changes (%) of the sanded specimens.

Specimen group	S ₀ (15 mm)		S ₁ (12 mm)		S ₂ (8 mm)		
	mean	st. dv.	mean	st. dv.	mean	st. dv.	
OAK	1. aroup	1.69	0.31	1.39	0.17	1.19	0.11
	2. aroup	1.97	0.37	1.38	0.21	1.33	0.20
	3. aroup	1.82	0.23	1.40	0.22	1.24	0.16
	4. aroup	2.16	0.31	1.43	0.16	1.34	0.18
SAPELE	5. aroup	1.76	0.19	1.03	0.11	1.02	0.13
	6. aroup	1.80	0.27	1.35	0.15	1.30	0.19
	7. aroup	1.96	0.15	1.15	0.11	1.08	0.11
	8. aroup	2.31	0.30	1.48	0.16	1.37	0.22

and sorption process and is not only related to relative humidity but also to the moisture history (Gunnar, 2011). The effect of the hysteresis is defined as a reduction of the apparent moisture capacity of wood (Rode & Clorius; 2004).

3.3. Effect of cyclic relative humidity changes on dimensional stability

The dimensional changes of cyclic conditioning groups is given in Table 12.

According to the test results, it can be mentioned that the dimensional stability of the specimens is improved with cyclic conditioning. Table 13 and 14 presents the results of dimensional changes of the cyclic conditioned oak and sapele specimens.

As it can be seen in Table 13 and 14 the dimensional change percentage of oak and sapele has decreased in all of the specimen groups after each conditioning. The most significant decrease occurred at the second conditioning. According to the results of Duncan's test, dimensional changes of the specimen groups are decreased and dimensional stability is improved after each conditioning. This finding is relevant to the hysteresis behavior of wood.

4. Conclusion

The results revealed that; the dimensional change of tangential specimens are higher than the radial specimens and wide specimens are higher than the narrow specimens.

According to the test results, dimensions of most of the specimen groups increase with increasing relative humidity and decrease with decreasing relative humidity. When the influence of grooves is evaluated with statistical analysis, the results revealed that grooves do not have a significant influence on the improvement of dimensional stability for individual parquet specimens.

Nevertheless, dimensional stability is improved with sanding application. According to statistical analysis, every group is different from each other and dimensional stability increased after each sanding. The most significant increase is obtained after the first sanding. It has been thought as an improve-

Table 10. Dimensional change (%) of the sanded oak specimens.

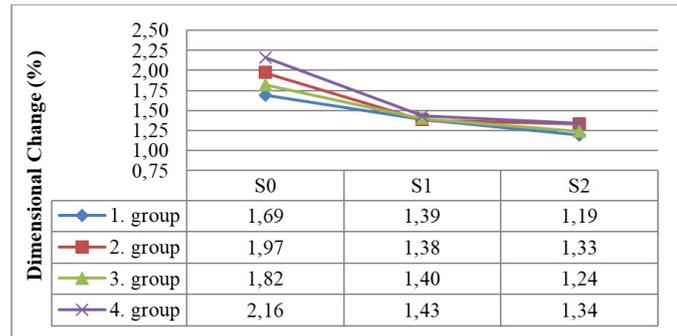
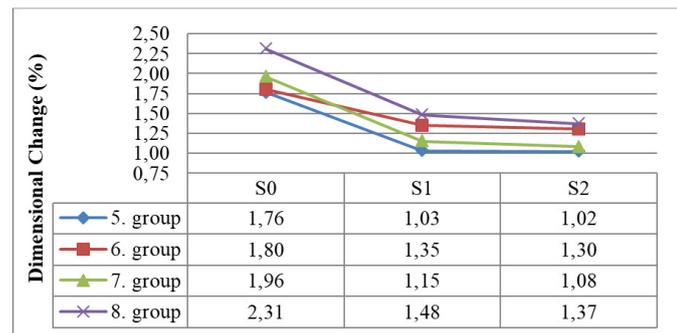


Table 11. Dimensional change (%) of the sanded sapele specimens.



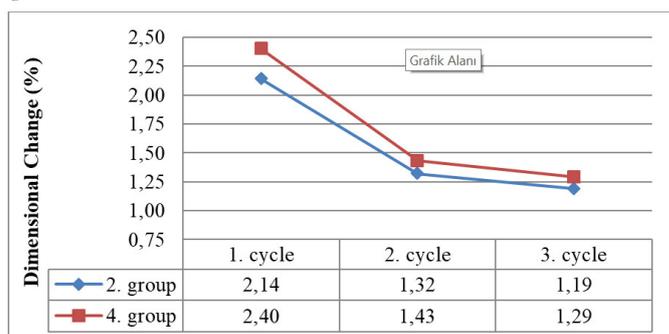
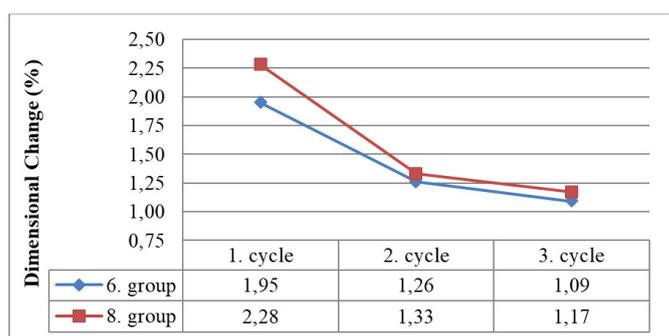
ment because of hysteresis effect. The dimensional stability of the specimen groups were also increased with cyclic relative humidity changes. Statistical analysis results revealed that, dimensional movement decreased after each conditioning. These findings are relevant to the hysteresis behavior of wood as well.

Due to the results of the tests and analysis, sanding and cyclic conditioning can be recommended for improving dimensional stability. These applications can also be a part of the manufacturing process. Narrow parquets with radial section is also recommended in flooring applications.

Although flooring materials are manufactured with grooves at the back for years, a satisfactory proof could not be obtained as an improvement in dimensional stability of grooved specimens. However, adhesives also have an influence in increasing the dimensional stability of grooved specimens. Further investigation on the dimensional stability of adhesives and grooves together is needed. Additional testing with different wood species and different relative humidity values would also be helpful in providing an additional step forward in dimensional movement behavior of wood.

Table 12. The dimensional changes (%) of the cyclic conditioned specimens.

Specimen group	G ₀ (1. cycle)		G ₀ (2. cycle)		G ₀ (3. cycle)	
	mean	st. dv.	mean	st. dv.	mean	st. dv.
2. group	2.14	0.69	1.32	0.20	1.19	0.15
4. group	2.40	0.36	1.43	0.14	1.29	0.11
6. group	1.95	0.27	1.26	0.40	1.09	0.07
8. group	2.28	0.28	1.33	0.14	1.17	0.11

Table 13. Dimensional change (%) of the cyclic conditioned oak specimens.**Table 14.** Dimensional change (%) of the cyclic conditioned sapele specimens.

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