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PROPERTIES OF TWO DIFFERENT THICKNESSES 3-PLY PLYWOOD OF TREE-OF-HEAVEN VENEERS

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ABSTRACT

Three-layered plywood panels are widely used for packing cases, furniture parts and other applications. Veneers of 1 mm and 1.5 mm nominal thickness, obtained by rotary cut of tree-of-heaven trunk, were used in the construction of 3-ply plywood. The mean thicknesses of the two plywood, used in this study, were 3.13 mm for the thinner one and 4.58 mm for the thicker one, respectively. According to the test results, the highest mean Bending strength value proved to have derived from the thin plywood (91.22 N/mm^2) and the thick one presented a little lower value of the respective strength (88.19 N/mm^2), while the thick plywood recorded higher mean Modulus of Elasticity value, compared to the corresponding value of the thin one. Referring to the Impact Bending strength, the thin plywood presented a little higher mean value (2.93 J/cm^2), than the thick plywood (2.60 J/cm^2), whereas the thick plywood was proved to have quite higher Screw Withdrawal capacity (33.35 N/mm^2), compared to the thin one (29.01 N/mm^2). Additionally, the thin plywood resulted in high Shear strength, both in the case when the plywood was tested in dry conditions and also, when it was tested after the immersion of the specimens in water. Finally, the thin plywood recorded higher Swelling percentage value, lower Absorption percentage value and lower percentage value of Permanent Swelling, compared to the thick plywood. Generally, according to these results it could be claimed that the thin plywood presents quite satisfying properties, compared to the corresponding thick plywood.

Key words: plywood, strength properties, tree-of-heaven, *Ailanthus altissima*, hygroscopic properties, withdrawal capacity

INTRODUCTION

Plywood can be produced in a great variety of types and quality, depending on the used raw material and the application that is used for. Interior plywood comprises furniture and wall panelling, while exterior plywood is appropriate for kitchen and bathroom applications. Another type of plywood is structural plywood, which is manufactured for applications where strength and durability are the primary factors. Structural plywood is used in the construction and building industry. Most commonly, plywood is used for formwork applications due to its strength, stability and tolerance to changes in temperature and moisture (Terzieva, 2008). Finally, plywood can also be used for transport and packaging structures.

A wide variety of species has been used in the construction of plywood products. The most commonly used softwoods for manufacturing plywood are firs, spruces and pines. For hardwood plywood, commonly used wood species include oak, poplar, maple, cherry, and larch. Poplar wood is commonly used in plywood due to its availability and low cost.

Plywood can be manufactured with the use of 3 or more layers and it is necessary that an uneven number of layers should be used. Several different thicknesses of plywood can be found in market. Much research has been carried out so far regarding the thin plywood properties and some of the most recent parts are the following: Baldassino et al. (1998) presented in their study the results of research on determining mechanical properties and main characteristic values of poplar plywood of three thicknesses 12, 18 and 24 mm by medium-sized test pieces. Aydin et al. (2006) evaluated the formaldehyde emission and some mechanical properties (bending strength, modulus of elasticity and shear strength) of poplar and spruce 3-ply plywood panels. The work of Vassiliou (1996) examined the effect of core veneer joints on bending strength of thin 3-ply poplar plywood of 3.5 mm in thickness. Panels used in the experiment were fabricated with rotary-peeled veneers, by using the urea-formaldehyde glue as binder and three different core veneer joints. Furthermore, the dimensional stability of Douglas fir and mixed beech-poplar 3-ply plywood of 5.7 mm in thickness were carried out by experimental measurements and simulations by Constant et al. (2003).

Ailanthus altissima (Miller) Swingle is a deciduous tree in the mostly tropical Quassia family, the one of *Simaroubaceae*. The genus is native from eastern Asia south to northern Australasia. It was introduced in Europe in the 1700s and has become widespread there (USDA Forest Service, 2006). Tree-of-heaven, as it is also widely known, has established in temperate climates throughout the world and the tree can be raised from both seeds and stumps. The species of Ailanthus is a fast growing species with an annual growth ring of 7.75 mm and its basic density is about 0.55 g/cm^3 (Barboutis and Vasileiou, 2009).

The young plants grow unusually fast in height, and the older ones increase noticeably in girth (Hu, 1970). It is an important timber and fuel wood tree, especially in China and is planted for timber and deforestation in New Zealand, Middle East, Eastern Europe, South America and other areas (Fryer, 2010). Ailanthus wood is yellowish white and well suited for cabinet making. The wood of mature ailanthus trees is of proven quality for cabinet work, musical instruments and other types of wooden ware (Kumar et al., 2010). This species of wood is easily worked with tools and glue and takes a finish well. Although the living tree tends to have quite flexible wood, this wood gets quite hard being properly dried and it has been proven that the strength of this species offers the ability to be used in the construction of a wide variety of wooden structures (Barboutis and Vasileiou, 2009). Concerning the properties of Ailanthus tree wood and specifically the properties of plywood constructed with Ailanthus veneers, extensive research has not been implemented so far.

The aim of this study was to determine the mechanical and hygroscopic properties of 3-ply plywood constructed with Ailanthus wood, using two different thicknesses for the specimens, in order to compare the property values of the two different plywood boards and therefore, to determine the proper applications for each plywood.

MATERIALS AND METHODS

The plywood specimens in this test were constructed with *Ailanthus altissima* (Mill.) Swingle wood taken from Ailanthus trees that were cut from the botanical garden of Phoinikas region in Thessaloniki (Facilities of Forestry Faculty). The samples were constructed with veneer sheets, which were rotary produced from logs 1 m in length. All the plywood specimens (Fig. 1) consisted of three plies, and were constructed in a small sized plywood industry in northern Greece (Genissea, Xanthi). Veneers of 1 mm and 1.5 mm nominal thickness, obtained by rotary cut of tree-of-heaven trunk, were used in the construction of 3-ply plywood, following the procedure of the plywood production, used in this plywood industry. Special attention has been paid in order to ensure the uniformity of the final plywood panels and the plywood production conditions (pressing time, adhesive amount etc.).

The adhesive used in the construction of the plywood panels was urea formaldehyde. Prior to the actual test, the panels were placed into a conditioning room and were allowed to reach a nominal equilibrium moisture content (EMC). Afterwards, the specimens of each test (12 per property test) were modulated in the appropriate dimensions, according to European Standards.

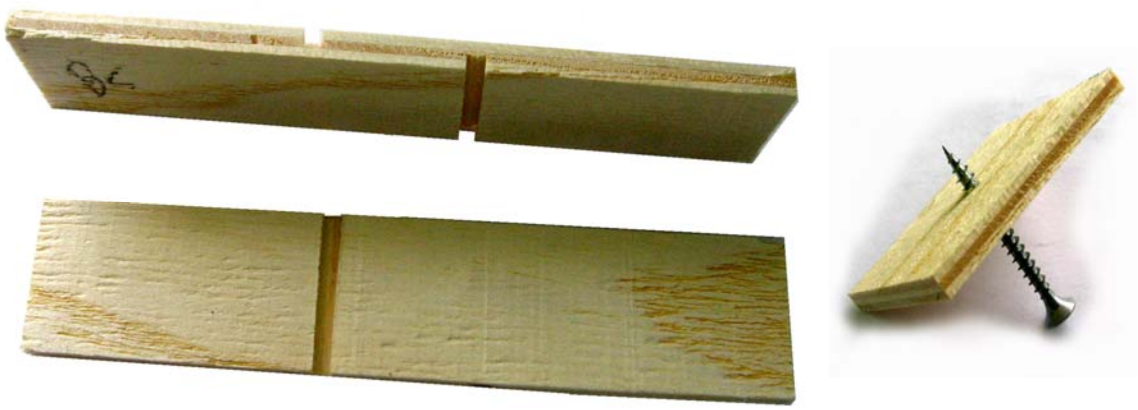

Figure 1. Surface appearance of the 3-ply Tree-of-Heaven plywood studied

Table 1. Plywood properties studied and the corresponding standards

PROPERTY	DIMENSIONS (cm) (width x length)	STANDARD
Density (Basic)	2 x 2.5	ISO 3131:1975
Moisture content	2 x 2.5	ISO 3130:1975
Bending Strength	5 x 20	EN 310:1993
Impact Strength	2.5 x 28	DIN 52189-1:1981
Shear strength	2.5 x 25	EN 314.1:2004
Swelling	5 x 5	EN 317:1993
Screw withdrawal capacity	5 x 5	EN 13446:2002

The properties, which were investigated in the two plywood of different thicknesses were Bending strength in length direction (Modulus of Rupture and Modulus of Elasticity), Shear strength, Impact bending strength, hygroscopic properties (Swelling, Absorption, Permanent Swelling) and Screw withdrawal capacity. The standards used for the tests are mentioned in the Table 1. The strength property tests were carried out on a Universal Testing Machine (SHIMADZU UH-300kNA) and the rate of crosshead-movement was adjusted at 5 mm/min, so that the maximum load was reached within 90 ± 30 sec throughout the test. The loading continued until a break of the specimen occurred. For the Screw Withdrawal Capacity test were used screws of 40 mm length, 4 mm nominal diameter and pilot holes were drilled in the plywood samples in perpendicular direction to the face of the sample, using a drill head of 2.5 mm. The shear strength tests were carried out with samples air conditioned and with samples after they had been immersed in water (20 ± 3^{o}C) for 24 hours, in order to check the suitability of these plywood in normal interior climate conditions, according to EN 314-1:2004 standard. The Impact Bending Strength tests were carried out on an Amsler Universal Wood Testing machine at 24 cm span with center loading. For each specimen, the impact by the falling pendulum occurred in the respected plane of static bending test. The hygroscopic properties were determined after emersion of the specimens in water of 20° temperature for 24 hours. The data from the property tests of the two plywood were grouped and examined by one-way Anova comparing the differences of means at the 0.05 level.

RESULTS AND DISCUSSION

The mean basic density (oven-dry weight / air-dry volume), mean moisture content and mean thickness of the two thicknesses 3-ply plywood tested are shown in the following table (Tab. 2). The basic density value of the thicker plywood appeared to be a little lower compared to the basic density of the thin one. This can be easily explained by the fact that the thicker plywood bears much more and larger splits across the grain, mainly in the internal surface of the veneers, caused by the rotary production. The moisture content of the thinner plywood was measured as 7.97%, while the respective value of the thicker 3-ply plywood was 8.22%. Besides, the mean thicknesses of the two plywood, were 3.13 mm for the thinner one and 4.58 mm for the thicker one, respectively. The thick plywood thickness (4.58mm) was 46.33% higher than the thickness of the thinner plywood (3.13mm).

Table 2. Basic properties of the two 3-ply plywood tested

Type of Plywood	Basic Density (g/cm³)	Moisture Content (%)	Thickness of Plywood (mm)
Thinner 3-ply plywood	0.688 (0.012)*	7.97 (0.14)*	3.13 (0.07)*
Thicker 3-ply plywood	0.634 (0.016)	8.22 (0.72)	4.58 (0.10)

* Mean values and Standard deviation in parenthesis

The results of the strength properties tested are indicated in the table below (Tab. 3).

Table 3. Strength properties of thin 3-ply plywood tested

Type of Plywood	Bending Maximum Load (N)	Bending Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Impact Strength (J/cm^2)	Screw Withdrawal Capacity (N/mm^2)
Thinner 3-ply plywood	295.20 (53.95)	91.22 (17.16)	8716.66 (1264.64)	2.93 (0.88)	29.01 (4.53)
Thicker 3-ply plywood	407.47 (20.89)	88.18 (5.29)	9870.34 (1003.67)	2.59 (0.67)	33.35 (5.08)

According to the results, the thinner tree-of-heaven plywood showed higher value of Bending strength (91.22 N/mm^2), compared to the respective thicker plywood, which marked 3.33% lower value (88.18 N/mm^2), but it should be mentioned that, the bending maximum load marked by the thicker plywood was 38.03% higher than the respective value of thinner one (Tab. 3). Besides, the thicker plywood excelled in Modulus of Elasticity (9870.3 N/mm^2), compared to the respective value of the thin one (8716.66 N/mm^2), which means approximately 13.23% higher Modulus of Elasticity value. According to variance analysis results, there was no recording of a statistically significant difference neither between the Bending strength value of the thin and the thick tree-of-heaven plywood, nor between the Modulus of Elasticity values of the two thicknesses plywood. According to EN 636:2003, the measured strength values of the thin plywood, in length direction, correspond to a classification of Ailanthus plywood as F60/E80, while the thick plywood correspond to a classification of Ailanthus plywood as F50/E90.

Relatively to the Impact Bending strength, the thin tree-of-heaven plywood resulted in 13.12% higher values (2.93 J/cm^2), than the thick plywood (2.59 J/cm^2). Therefore, there was no recording of a statistically significant difference between the Impact bending strength value of the thinner tree-of-heaven plywood and the corresponding value of the thicker one.

In the case of Screw Withdrawal Capacity, the thicker tree-of-heaven plywood exhibits also satisfying strength values (33.35 N/mm^2), which corresponds to 14.96% higher values than the thinner plywood (29.01 N/mm^2). The thicker plywood did not seem to record statistically significant differences between its screw withdrawal capacity value and the corresponding value of the thinner one.

Table 4. Shear strength and wood failure of thin 3-ply plywood

Type of Plywood	Dry (in standard atmosphere)		Wet (immersed for 24 h in water)	
	Shear Strength N/mm^2	Wood Failure %	Shear Strength N/mm^2	Wood Failure %
Thinner 3-ply plywood	2.17 (0.33)	71.67 (10.52)	2.24 (0.37)	61.67 (14.03)
Thicker 3-ply plywood	1.52 (0.23)	41.11 (33.81)	1.17 (0.35)	20.00 (8.16)

The quality of plywood specimens was also evaluated by the bonding line shear test of the adhesive. Taking into account the mean Shear strength and also, the mean apparent cohesive failure of the plywood specimens recorded, both the plywood satisfy the criteria of the EN 314.02:1994 standard for class 1 of bonding quality (dry condition). Between the two plywood, lower Shear strength (Tab. 4) appeared to be a feature of the thick plywood, either in the case when it was tested in air dry (1.52 N/mm^2) or in wet condition (1.17 N/mm^2), while the thinner plywood demonstrated higher Shear strength values both in dry (2.17 N/mm^2) and wet condition (2.24 N/mm^2). Concerning the Shear strength values, there was a statistically significant difference between the thinner and the thicker tree-of-heaven plywood values, whether the specimens were tested in wet or dry condition. The strength values of the thinner plywood appeared to be higher when the samples were tested in wet condition but without recording a statistically significant difference, while the strength values of the thicker plywood proved to be higher when the samples were tested in air dry conditions.

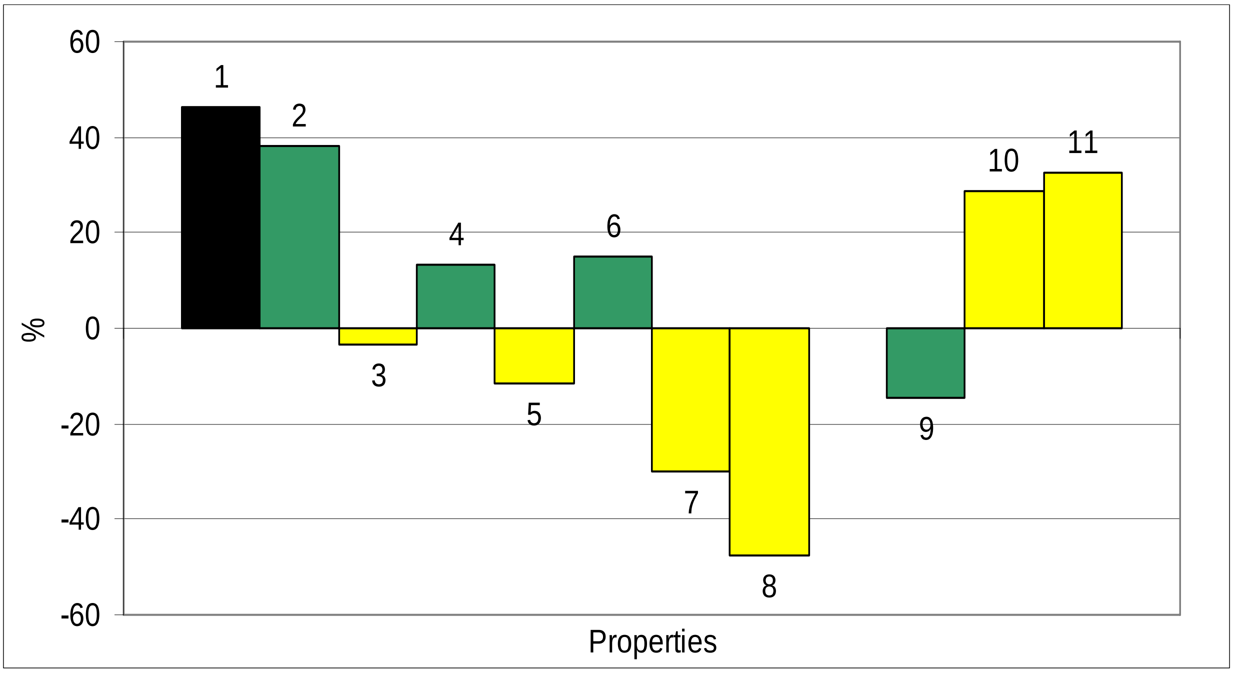

Figure 2. Increase or decrease Percentage of the thicker plywood properties, compared to the thin one (1.Thickness (mm), 2.Maximum Rupture Load (N), 3.Bending Strength (N/mm^2), 4.Modulus of Elasticity (N/mm^2), 5.Impact Bending Strength (J/cm^2), 6.Screw Withdrawal Capacity (N/mm^2), 7.Shear Strength (Dry) (N/mm^2) 8.Shear Strength (Wet) (N/mm^2), 9.Swelling (%), 10.Permanent Swelling (%), 11.Absorption (%)

In the case of hygroscopic properties (Tab. 5), the thinner tree-of-heaven plywood revealed a little higher mean Swelling percentage value (6.76%), than the thicker one (5.78%), while the thicker plywood has shown much higher average Absorption percentage (59.82%), compared to the corresponding value of thinner plywood (45.13%). Finally, quite noticeable is the fact that the thinner tree-of-heaven plywood presented lower percentage of Permanent Swelling (2.09%), compared to the thicker plywood, which marked higher percentage of Permanent Swelling (2.69%), about 28.71% higher. According to variance analysis results, the Absorption percentage value of the thinner tree-of-heaven plywood presented statistically significant difference from the respective value of the thicker plywood, while the Swelling and the Permanent Swelling percentage value of both the thinner and thicker tree-of-heaven plywood did not mark significant differences.

Table 5. Hygroscopic properties of thin 3-ply plywood

Type of Plywood	Swelling %	Permanent Swelling %	Absorption %
Thinner 3-ply plywood	6.76 (1.14)*	2.09 (0.24)	45.13 (2.17)
Thicker 3-ply plywood	5.78 (1.08)	2.69 (0.88)	59.82 (2.26)

* Mean values and standard deviation in parenthesis

As it can easily be seen in Fig. 2, the increase of the plywood thickness did not promote all the properties (strength and hygroscopic properties) that were investigated in this test. The properties that were influenced by the thickness increase in a positive way, pictured in the figure 2 with darker color, were the following: Maximum Rupture Load, Modulus of Elasticity, Screw Withdrawal Capacity and Swelling. In contrast, the Bending Strength, the Impact

Bending Strength, the Shear strength tested either in dry or in wet conditions, the Permanent Swelling and the Absorption presented a negative influence by the increase of the plywood thickness and these properties are pictured in figure 2 with lighter color. It should be mentioned, that the change of properties recorded, using higher plywood thickness, was not proportional in any of the cases to the change of plywood thickness.

The fact that the thinner 3-ply tree-of-heaven plywood presented higher values concerning some properties tested, compared to the thicker plywood, is attributed mainly to the thin plywood higher mass density (same adhesive amount used in the adhesive surfaces). Probably, the remarkably higher density of the thinner tree-of-heaven plywood resulted in its higher strength values (some of the properties) and better hygroscopic performance. The appropriate thickness for each plywood panel, depends on the types of load acting on the wood structure, the conditions that the structure is exposed to and therefore, the strength and hygroscopic properties required for the final use.

CONCLUSIONS

Ailanthus altissima (tree-of-heaven) is a recently developed wood species used in plywood construction, whereas other species such as poplar wood has been used traditionally in plywood construction for many years. The wood of mature ailanthus trees is of proven quality and therefore, can be used in the construction of a wide variety of wooden structures. The conclusion, which can be drawn after the completion of this study, is that tree-of-heaven plywood with 3.13 mm nominal thickness present quite satisfying values of mechanical and hygroscopic properties, compared to the respective 3-ply plywood of the same species with 4.58 mm nominal thickness. Higher Bending strength values and a little lower values of Modulus of Elasticity were recorded in thinner plywood, compared to the thicker ones. Also, remarkable high values of Shear strength and Impact bending strength were revealed, compared to the thicker plywood, and the two tree-of-heaven plywood both appear to surpass the requirements of EN standards for use in normal interior climate. A little lower Screw Withdrawal capacity proved to be a feature of thinner plywood, compared to the respective thicker one. Furthermore, the Absorption and the Permanent Swelling value of the thinner tree-of-heaven plywood appeared to be quite limited, which allows the product to be used and remain exposed in environments of high humidity.

Additional research is necessary in order to fulfil the requirements of the industry world, as well as the consumers' growing interest concerning the strength and other properties of tree-of-heaven wood and plywood constructed with this species. Thereby, the opportunity to conclude to the proper applications for each plywood would be provided according to the load types, the corresponding resistance and strength properties that each thickness plywood has recorded.

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