PROPERTIES OF THIN 3-PLY PLYWOOD CONSTRUCTED WITH TREE-OF-HEAVEN AND POPLAR WOOD

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ABSTRACT: Thin 3-ply plywood of approximately 3.0 mm in thickness is commonly constructed with poplar wood for packing cases and some furniture applications. The aim of this research was to study the mechanical and hygroscopic properties of the thin 3-ply plywood made with tree-of-Heaven veneer in order to compare them to the corresponding properties of the thin 3-ply poplar plywood. According to the results tree-of-heaven plywood showed higher values in all properties tested compared to the poplar plywood samples. Specifically, Bending strength marked a 49.9% higher value (tree-of-heaven 91.22 N/mm^2 – poplar 60.85 N/mm^2), Modulus of Elasticity marked a 39.4% higher value (tree-of-heaven 8716.66 N/mm^2 – poplar 6251.88 N/mm^2), Screw withdrawal capacity marked a 127.9 % higher values (tree-of-heaven 29.01 N/mm^2 – poplar 12.73 N/mm^2), whereas Impact Bending strength resulted in 190.1% higher values (tree-of-heaven 2.93 J/cm^2 – poplar 1.01 J/cm^2), and Shear strength resulted in remarkable higher values in both air dry condition (tree-of-heaven 2.17 N/mm^2 – poplar 0.94 N/mm^2) and wet condition (tree-of-heaven 2.24 N/mm^2 – poplar 1.16 N/mm^2). In the case of Hygroscopic properties the tree-of-heaven plywood revealed a little higher swelling percentage (6.76%) than the poplar plywood (5.05%), while the poplar plywood showed much higher percentage of mean absorption (77.51%) compared to the corresponding value of tree-of-heaven plywood (45.13%). Conclusively, the tree-of-heaven wood used in the thin 3-ply plywood constructive record quite satisfying values of strength and hygroscopic properties.

Key words: plywood, tree-of-heaven, poplar, strength properties.

1. INTRODUCTION

Ailanthus altissima (Miller) Swingle is a rapidly growing, deciduous tree in the mostly tropical Quassia family, the one of Simaroubaceae (USDA Forest Service, 2006). The genus is native from eastern Asia south to northern Australasia. It was introduced in Europe in the 1700s and has become widespread there. Tree-of-heaven 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).

Tree-of-heaven has some characteristics that make it undesirable within both urban and forested areas. It is a fast-growing tree and a prolific seeder, that can take over sites, replacing native plants and forming dense thickets (Fryer, 2010). Ailanthus also produces chemicals that prevent the establishment of other plant species nearby. Its root system also may be extensive and has been known to cause damage to sewers and foundations. Tree-of-heaven invasiveness may be due, in part, to its unusually high capacity to photosynthesize and its high water-use efficiency. These abilities, coupled with pollution, temperature and drought tolerance, make tree-of-heaven especially successful in disturbed urban environments and may also help it invade wild lands (Fryer, 2010). However, it is generally more common in urban, suburban, and rural than wild environments (USDA Forest Service, 2006). As well, Ailanthus has been used to re-vegetate areas where acid mine drainage has occurred and it is widely used for forage and erosion control.

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 afforestation 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 wood is easily worked with tools and glue and takes a finish well. Although the live 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 wood offers the ability to be used in the construction of a wide variety of wooden structures (Barboutis and Vasileiou, 2009).

Plywood can be used for many different purposes. 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. Poplar wood is commonly used in plywood due to its availability and low cost. The poplar plywood board is classified as one of the most popular types of plywood for packing cases and some furniture applications. 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.

Many researches have been carried out so far regarding the plywood properties and some of the most recent ones concerning poplar species are the following. Baldassino et al. (1998) present 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).

The aim of this study was to determine the mechanical and hygroscopic properties of newly developed 3-ply plywood constructed of Ailanthus wood and their comparison with conventional 3-ply plywood properties constructed with poplar wood, both of approximately 3.0 mm in thickness.

2. MATERIALS AND METHODS

Experiments were carried out with two different species of wood. Half of the specimens were constructed with Ailanthus altissima (Mill.) Swingle, whereas the other half were constructed with poplar wood (Poplar clone I-214). The Ailanthus trees were cut from the botanical garden of Phoinikas region in Thessaloniki (Facilities of Forestry Faculty), whereas the poplar wood was obtained from plantations in the area of Xanthi (North Greece). The samples were constructed with veneer sheets, which were rotary produced from logs 1 m in length. All the plywood specimens (Photo 1) of approximately 3.0 mm in thickness consisted of three plies, and were constructed in a small sized plywood industry in northern Greece (Genissea, Xanthi).

The adhesive used in the construction of the plywood samples was urea formaldehyde. Prior to treatment, the specimens were placed into a conditioning room and were allowed to reach a nominal equilibrium moisture content (EMC). Afterwards, the specimens of each test (15 per property test) were modulated in the appropriate dimensions, according to European Standards.

Photo 1. Surface appearance of the two 3-ply plywood studied
(Poplar – left, Tree-of-Heaven – right).

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 different wood species plywood were Bending strength in length direction (Modulus of Rupture and Modulus of Elasticity), Shear strength, Impact bending strength, Swelling and Screw withdrawal capacity. The standards used for the tests are mentioned in the Table 1. The strength properties 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 1.5±0.5 min throughout the test. The loading continued until a break of the specimen occurred. The shear strength tests were carried out with samples air conditioned and with samples after they had 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 plywood properties tests were grouped and examined by one-way Anova comparing the differences of means at the 0.05 level.

3. RESULTS AND DISCUSSION

The basic density (oven-dry weight/air-dry volume), moisture content and thickness of the two thin 3-ply plywood tested are shown in the following Table 2.

Table 2

Basic properties of thin 3-ply plywood tested

Wood species of plywood	Basic Density (g/cm^3)	Moisture content (%)	Thickness of Plywood (mm)
Tree-of-heaven	0.688 (0.012)*	7.97 (0.14)*	3.13 (0.07)*
Poplar	0.374 (0.027)	8.48 (0.16)	2.92 (0.08)

* Mean values and Standard deviation in parenthesis

The results of the strength properties tested are indicated in the Table 3 below.

Table 3

Strength properties of thin 3-ply plywood tested

Wood species of plywood	Bending Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Impact Strength (J/cm^2)	Screw withdrawal capacity (N/mm^2)
Tree-of-heaven	91.22 (17.16)	8716.66 (1264.64)	2.93 (0.88)	29.01 (4.53)
Poplar	60.85 (10.37)	6251.88 (936.72)	1.01 (0.48)	12.73 (3.11)

According to the results, tree-of-heaven plywood showed higher values in Bending strength (91.22 N/mm^2), compared to the poplar plywood which marked 33.3% lower value (60.85 N/mm^2) and furthermore, the tree-of-heaven plywood excelled in Modulus of Elasticity (8716.66 N/mm^2), compared to the poplar plywood (6251.88 N/mm^2), which means approximately 24.3% lower value of Modulus of Elasticity. According to variance analysis results, it was recorded a statistically significant difference between the Bending strength value of tree-of-heaven and poplar plywood, while there was not a significant difference between the Modulus of Elasticity value of tree-of-heaven plywood, from the respective value of the poplar plywood. According to EN 636:2003, the measured values of the strength in length direction correspond to a classification of Ailanthus plywood as F60/E80, whereas of poplar plywood as F40/E60.

In the case of Screw Withdrawal Capacity, tree-of-heaven plywood exhibits also satisfying strength values (29.01 N/mm^2), which corresponds to 128% higher values than the poplar plywood (12.73 N/mm^2). The tree-of-heaven plywood seemed to record statistically significant differences in its screw withdrawal capacity values, from the corresponding value of poplar plywood.

Relatively to the Impact Bending strength the plywood constructed with tree-of-heaven wood resulted in 190% higher values (2.93 J/cm^2) than the plywood constructed with poplar plies (1.01 J/cm^2). Therefore, it was recorded a statistically significant difference between the Impact bending strength value of tree-of-heaven plywood and the corresponding value of the poplar plywood.

Very low Shear strength (Table 4) appeared to be a feature of the plywood constructed with poplar, whether it was tested in air dry (0.94 N/mm^2) or wet condition (1.16 N/mm^2), while the tree-of-heaven plywood demonstrated higher Shear strength values both in dry (2.17 N/mm^2) and wet condition (2.24 N/mm^2). The strength values of both species plywood appeared to be higher when the samples tested in wet condition but without a statistically significant difference.

Table 4

Shear strength and wood failure of thin 3-ply plywood

wood species 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 %
Tree-of-heaven	2.17 (0.33)	71.67 (10.52)	2.24 (0.37)	61.67 (14.03)
Poplar	0.94 (0.19)	86.25 (6.44)	1.16 (0.30)	76.25 (14.64)

The bonding quality of these plywood satisfy the criteria of mean shear strength and the mean apparent cohesive wood failure for the class 1 (dry condition), according to EN 314-2:1993.

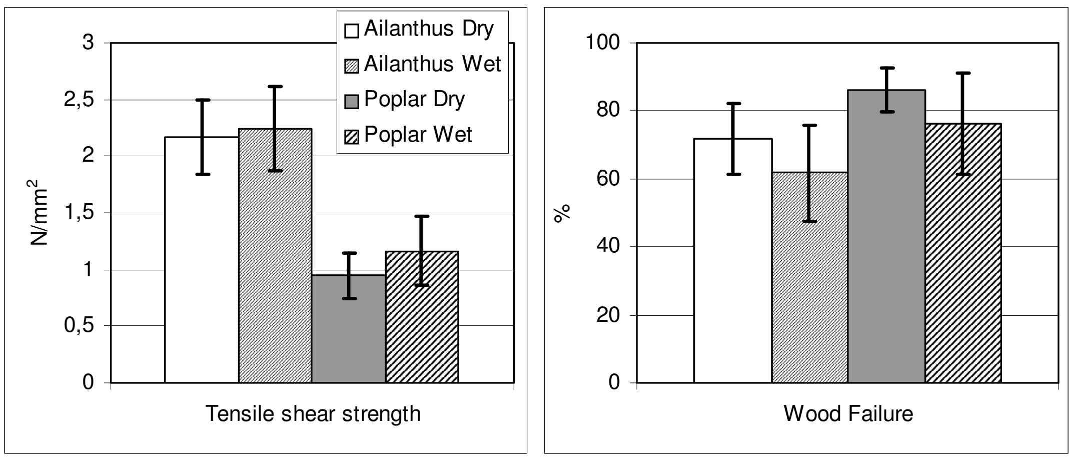

Fig. 1 Shear strength and wood failure (dry and wet plywood).

Relatively to shear strength values, there was a statistically significant difference between the tree-of-heaven plywood value, whether it was used in wet or dry condition and the poplar plywood value, whether it was used dry or wet poplar plywood.

Table 5

Hygroscopic properties of thin 3-ply plywood

wood species of plywood	Swelling %	Permanent Swelling %	Absorption %
Tree-of-heaven	6.76 (1.14)*	2.09 (0.24)	45.13 (2.17)
Poplar	5.05 (1.11)	1.29 (0.44)	77.51 (8.44)

* Mean values and standard deviation in parenthesis

In the case of hygroscopic properties (Table 5), the tree-of-heaven plywood revealed a little higher average of swelling percentage (6.76%), than the poplar plywood (5.05%), while the poplar plywood has shown much higher percentage of average absorption (77.51%), compared to the corresponding value of tree-of-heaven plywood (45.13%). Finally, quite noticeable is the fact that the tree-of-heaven plywood gave higher percentage of permanent swelling (2.09%), compared to the poplar plywood, which marked lower percentage of permanent swelling (1.29%), about 38% lower.

According to variance analysis results, the absorption percentage value of tree-of-heaven plywood presented statistically significant differences from the respective value of the poplar plywood, while the Swelling and the permanent Swelling percentage value of both the tree-of-heaven and poplar plywood did not mark significant differences.

The higher values of all properties tested of the tree-of-heaven 3-ply plywood compared to the poplar 3-ply plywood are attributed mainly to its higher mass density. The remarkable higher density of the tree-of-heaven plywood (84%) in comparison to the poplar plywood resulted in its higher strength values and better hygroscopic performance.

4. CONCLUSIONS

Ailanthus altissima (tree-of-heaven) is a recently developed wood species used in plywood construction, whereas poplar wood has been used traditionally in plywood construction for many years. The conclusion, which can be drawn from the completion of this research, is that tree-of-heaven used in the plywood construction record quite satisfying values of mechanical properties. Bending strength and Modulus strength of tree-of-heaven plywood was two classes better than poplar plywood. Also remarkable high values of Shear strength, Impact bending strength and Screw withdrawal capacity were revealed compared to the poplar plywood therefore, tree-of-heaven plywood appears to surpass the requirements of EN standards for use in normal interior climate. Furthermore, the swelling value of tree-of-heaven plywood appeared to be quite limited, which allows the product to be used and 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.

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