BIOLOGICAL AND WOOD PROPERTIES OF *AILANTHUS ALTISSIMA* (MILL.) SWINGLE

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Abstract

We studied the growth in height, diameter, volume and the most important wood properties of 11-year old *Ailanthus altissima* (Mill.) Swingle trees grown at the Research station for fast-growing species near Svishtov, Bulgaria. We found that the height growth was most intensive during the first years with maximum rate in the 5th year. The diameter and volume growth were continuous and by the 11th year still had not reached a decrease in the rate. The wood density at air-dry condition (w = 7.5%) was 620 kg.m^{-3}, at absolutely dry condition (w = 0%) was 580 kg.m^{-3}, while at maximally saturated with water (density in row condition) it was 1045 kg.m^{-3}. The volume shrinkage was 14.85%. Head hardness, studied following Brinel method (in direction parallel to the grains), was 83.41 N.mm^{-2}, the hardness in radial direction was 61.48 N.mm^{-2} and in tangential direction – 52.03 N.mm^{-2}. The bending strength (MOR) of air-dry wood was 71.11 N.mm^{-2}. The modulus of elasticity (MOE) was 11.906 GPa. The compression strength parallel to the fibres was 55.83 N.mm^{-2}. The shear strength parallel to the fibers in tangential plain was 14.41 N.mm^{-2}, while in radial plain was 13.65 N.mm^{-2}. Our results show that *Ailanthus altissima* is underestimated fast-growing species, whose wood can be successfully used for production of paper and furniture. Therefore we consider appropriate a recommendation to start trials with establishment of experimental plantation.

Key words: timber properties, density, hardness, bending strength, gluing strength.

Introduction

The native land of *Ailanthus altissima* is China. The word "ailanthus" derives from the Moluccan name "aylanto" and means "tree-of-heaven". The word "altissima" means very tall (Kowarik and Saumel 2007). Besides the characteristics of the tree, this also reflects the very long leaves, which can reach more than 1 m in length. It was introduced in Europe in 1751 (in England) and in America in 1874 (Alden 1995). In these years this tree was planted in parks and gardens. *Ailanthus altissima* is fast-growing tree species. In its first year it can reach 3 m in height. For the duration of their life individuals can reach 20–30 m in height and 0.6–0.8 m in diameter (Hu 1979). The trees produce wide crown with thick and sparsely situated branches. At early age the bark is smooth, yellowish-gray or brown-gray in color. At higher age the bark is shallow and with longitudinal cracks. The leaves are decompound, i.e. the prolonged oval leaf blades are bilaterally and horizontally situated over thin sticks with 1 m length. The leaves are rich in tannins and when ground with fingers the *Ailanthus* leaves foul odor. The flowers have similar odor. The *Ailanthus* tree blossoms in June. The flowers are small greenish-yellow, unisexual or synoecious, gathered in heavy, straight broom racemes. The fruit is a nut with one winglet. The seeds become ripe in October and spend the winter on the tree (Hu 1979, Swearingen 2009). They are easily transported by wind. The species reproduces easily vegetatively from root and stem sprouts and generatively with abundant seeds. Characteristic biological feature of *Ailanthus altissima* is that the trees form huge quantities of root suckers. Its root system is developed in both horizontal and vertical direction (Kowarik and Saumel 2007). It settles down in fertile soils, but can be found also on poor soils. The trees are also tolerant to calcium content in the soil. *Ailanthus* prefers sunny locations. It tolerates sudden temperature changes. Due to the ability of the species to colonize rapidly open territories and its wide tolerance to soil conditions, many trials for evaluation of its potential as erosion control species were established in Bulgaria. Often the species displays pioneer character and in some regions of the world (including parts of Bulgaria) is considered as “invasive” (Swearingen 2009). Especially in abandoned city environment it can quickly colonize wide territories. An important feature that gives *Ailanthus* advantage in this respect is that the tree is allelopathic and can limit the growth of other species by releasing plant toxins (Lawrence et al. 1991). Yet, the species is still widely used as a garden tree and as economically important one. Among the features that make it valuable are medical uses of the plant, use of the wood for furniture production and energy source, and for breeding of the moth *Samia cynthia* from which valuable “eri silk” is produced (Hu 1979). The species is spread in countries all over the world in both warm and temperate zones. In Bulgaria *Ailanthus* was introduced probably at the end of 19^{th} or at the beginning of 20^{th} century for the purpose to lay out city lawns, parks and gardens. A great amount of *Ailanthus* trees at the age of 80 years are preserved. They are in good condition with diameters from 40 to 94 cm. The oldest tree can be seen in Sofia behind the King`s palace. Probably this venerable tree is from the period of the initial garden plantings. Its diameter is 116.9 cm and the height is 18 m. This changes the former perception that the maximum age that the species may reach in Bulgaria is 40–50 years (Enchev 1975). During the second half of the 20th century experimental *Ailanthus* plantations were established in the Research station for fast-growing species near the village of Vardim close to Danube river. The purpose was to test the growth of this fast-growing species under controlled conditions. Yet, despite initial data showing fast growth and high potential for production of wood and biomass, up to this moment *Ailanthus* was neglected especially from the point of view of wood production. The main reason is the common perception in Bulgaria that the wood is of low quality and not usable for practical purposes. Yet, wood properties were studied in other countries. A study in the Madison laboratory (Alden 1995) reported that *Ailanthus* stems have wide core, narrow light grey-reddish heartwood and wide yellowish-white sapwood (Moslemi and Bhagwat 1970). The wood has ring porous structure. Tracheas have big diameter and are arranged in narrow stripe spring zone, which can be seen at the beginning of the annual ring with a naked eye. The annual rings are wide, the latewood takes 90% of the ring. In the longitudinal tangential section of the stem core rays can be seen with a naked eye. Their appearance resembles glittering brief stripes. Anatomic sections revealed that core rays are monostichous and polystichous with brief spindle shape (Enchev 1975). A study of wood properties made by Alden (1995) demonstrated that the specific gravity at 12% humidity was 0.531 $g.cm^{-3}$ and density in air-dry condition was 537-617 $kg.m^{-3}$. The modulus of elasticity (MOE) during bending unseasoned wood was 6.343 GPa and of dry wood it was 10.48 GPa. Modulus of rupture (MOR) or border bending strength of unseasoned wood was 41.37 MPa and of dry wood it was 81.361 MPa. Pressure strength parallel to the fibers of unseasoned wood was 16.548 MPa and of dry wood it was 36.268 MPa. Pressure strength cross to the fibers of unseasoned wood was 2.62 MPa and of dry wood it was 7.791 MPa. Shear strength parallel to the fibers of unseasoned wood was 7.239 MPa and of dry wood it was 15.444 MPa (Hoshovsky 1988). Here we aim at studying the wood properties of *Ailanthus* trees grown under controlled conditions in Bulgaria. Our purpose was to obtain data for the most important technical characteristics and thus to provide initial data about the potential of the species for fast wood production.

Material and Methods

We used the timber of 11-years old *Ailanthus* tree from the seed-garden in the village of Vardim. We did annual measurements of the height and diameter of the tree. At the time it was felled the sample tree had diameter 16 cm and height 12.6 m. The stem was cut to planks with 60 mm thickness at each meter and they were left outdoors covered by shelter. Thus they were subjected to natural drying under the influence of the weathering factors for a period of three years. Then we did standard stem analysis measuring the tree ring increment for each plank. From the central planks we made samples which were used to determine the most important physical and mechanical properties. In the study we followed standard procedures according to the Bulgarian standards and correspondent with DIN 1052. Gluing properties of *Ailanthus* wood were studied following regulations of BDS EN 204, BDS EN 205, BDS EN 301 and BDS EN 302. Gluing was done in laboratory conditions in cold press with glue Jowacol 107 and in hot press (125°C) with glue Prefere 4114. The used specific pressure was 0.5 MPa. The adhesion strength of protective decorative films to wood surface was examined according to a method that is regulated in BDS 13088:86 and BDS EN 4624.

Results

Tree growth

The height growth was most intensive during the first 4 years. It reached its maximum rate in the 5th (Fig. 1). The rate of diameter increment was steady until the 8th year and then decreased slightly (Fig. 2).

The diameter growth at 1.3 m height was as follows: at the 1-st year – 0.8 cm; at the 2-nd year – 2.5 cm; at the 3rd – 4.1 cm; at the 4th – 5.8 cm; at the 5th – 7.65 cm; at the 6th – 9.55 cm; at the 7th – 11.6 cm; at the 8th – 13.3 cm; at the 9th – 14.6 cm; at the 10th – 16.3 cm and at the 11th – 17.7 cm without bark (fig. 2). The curve of volume increment until the age of 11 years showed ascending tendency and culmination has not yet been reached (fig. 3). Our results demonstrate that *Ailanthus* is indeed a fast growing species with high accumulation of wood in the first one to two decades of growth. The only faster growing valuable trees in Bulgaria are poplar cultivars, which can reach up to 20 m height at age of 11 years (data for cultivar "I-214" grown in the same location).

Wood properties

During the initial visual analysis of wood samples we determined that the annual rings were very wide in the first five years. In that period they were 15–17 mm. In the next few years they were slightly narrower (11–13 mm). In longi-

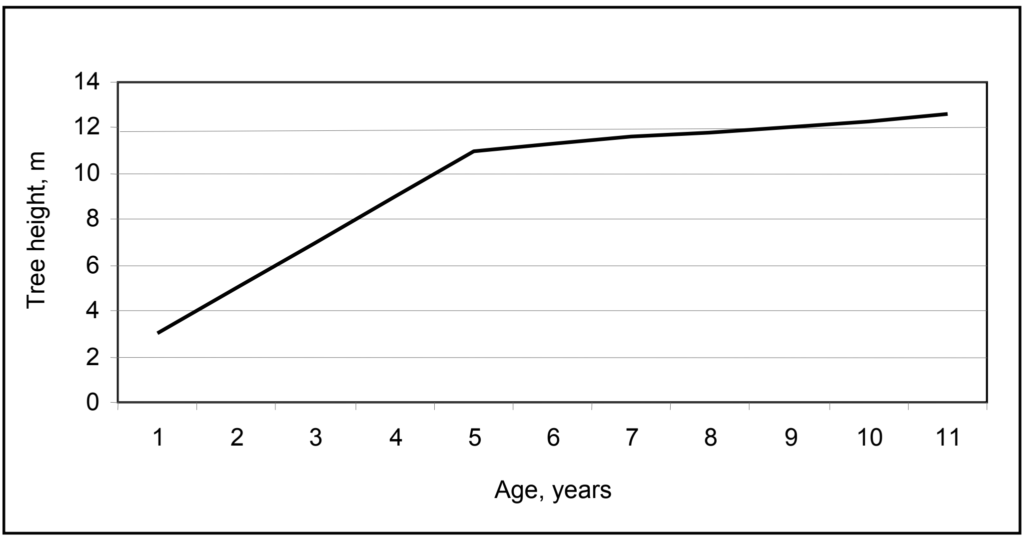

Fig. 1. Height growth of 11-years old *Ailanthus* tree.

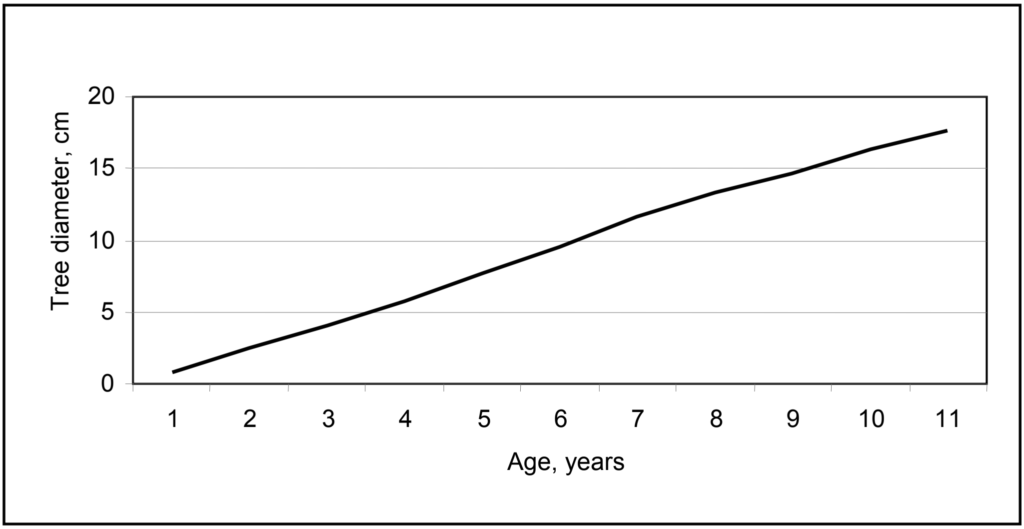

Fig. 2. Diameter growth of 11-years old *Ailanthus* tree.

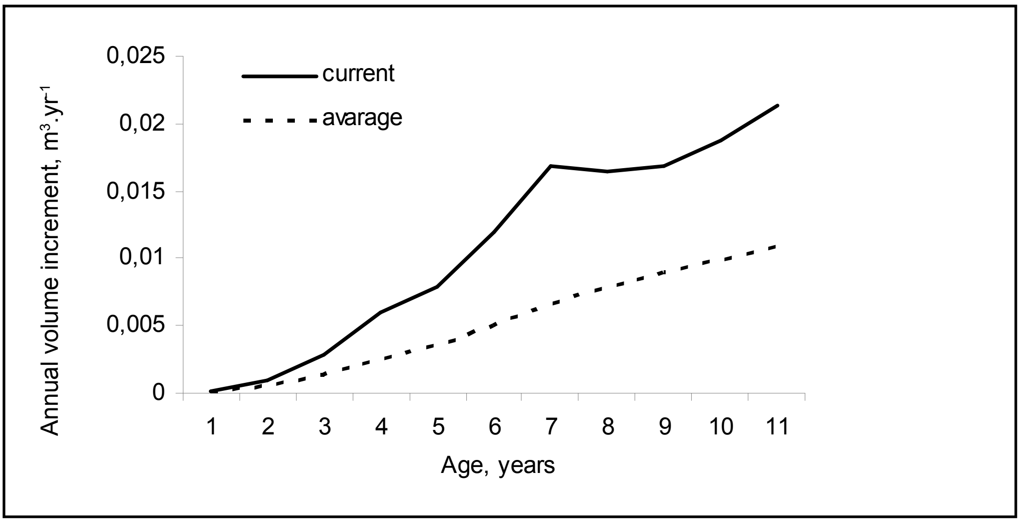

Figure 3. Annual volume increment of 11-years old *Ailanthus* tree.

tudinal sections the extract substances in tracheas could be seen with a naked eye. They resembled glittering yellowish-orange crystals. The average values of the studied physical and mechanical properties of *Ailanthus* timber are shown in Table 1. In respect to density and static hardness it was estimated that *Ailanthus* timber refers to the group with average density and hardness. The wood density at air-dry condition (w=7.5%) was 620 kg.m^{-3}. When the wood was in condition with the highest degree of water content, the density

Table 1. Physical and mechanical properties of the timber of 11-years old *Ailanthus* tree.

No	Property	n	Variation indexes				
			Aver.	St.D.	Error	V, %	P, %
1	Density in row condition, kg.m^{-3}	81	1,045	23.9	2.66	2.3	0.25
2	Density in dry condition, kg.m^{-3}	81	620	23.5	2.61	3.8	0.42
3	Density in abs.dry condition, kg.m^{-3}	81	580	21.0	2.33	3.6	0.41
4	Conventional density, kg.m^{-3}	81	485	24.8	2.75	5.1	0.57
5	Water absorption, %	81	115	3.85	0.43	3.3	0.37
6	Tangential swelling, %	81	12.34	1.89	0.21	15.3	1.70
7	Radial swelling, %	81	6.41	1.45	0.16	22.6	2.51
8	Swelling in size, %	81	19.51	2.83	0.31	14.5	1.61
9	Tangential shrinkage, %	81	10.82	1.43	0.16	13.2	1.46
10	Radial shrinkage, %	81	6.12	1.06	0.12	17.3	1.92
11	Shrinkage in size, %	81	17.09	1.45	0.16	8.48	0.94
12	Head hardness-Yanka, N.mm^{-2}	64	59.68	4.25	0.53	7.12	0.89
13	Radial hardness-Yanka, N.mm^{-2}	64	44.07	4.52	0.56	10.2	1.28
14	Tangential hardness-Yanka, N.mm^{-2}	64	54.07	4.73	0.59	8.75	1.09
15	Head hardness-Brinel, N.mm^{-2}	64	83.41	16.9	2.11	20.3	2.53
16	Radial hardness-Brinel, N.mm^{-2}	64	61.48	21.7	2.71	35.3	4.41
17	Tangential hardness-Brinel, N.mm^{-2}	64	69.23	14.2	1.78	20.5	2.56
18	Compression strength parallel the direction of fibers, N.mm^{-2}	64	55.83	3.63	0.45	6.5	0.81
19	Tangential shear strength parallel the direction of fibers, N.mm^{-2}	64	14.41	1.68	0.21	11.6	1.45
20	Radial shear strength parallel the direction of fibers, N.mm^{-2}	64	13.65	2.64	0.33	19.3	2.42
21	Radial split strength parallel the direction of fibers, kN.m^{-1}	64	85.18	17.7	2.21	20.7	2.59
22	Tangential split strength parallel the direction of fibers, kN.m^{-1}	64	106.4	20.4	2.55	19.2	2.39
23	Static bending strength, N.mm^{-2}	64	71.11	8.56	1.07	12.1	1.51
24	Modulus of elasticity during static bending, N.mm^{-2}	64	11,906	1,873	234	15.7	1.97

Symbol: n – quantity of samples.

was 1045 kg.m^{-3}. The density at absolutely dry condition (w=0%) was 580 kg.m^{-3}. The conventional density was 485 kg.m^{-3}. Head hardness, defined by the Yanka method, was 59.68 N.mm^{-2}. Head hardness, defined by the Brinel method, was 83.41 N.mm^{-2}. The cross radial hardness, defined by the Yanka method, was 44.07 N.mm^{-2}. The cross radial hardness, defined by the Brinel method, was 61.48 N.mm^{-2}. The cross tangential hardness, defined by the Yanka method, was 54.07 N.mm^{-2}. The cross tangential hardness, defined by the Brinel method, was 69.23 N.mm^{-2}. The hardness in tangential direction, i.e.

in radial section (radial cross hardness) had lower values in comparison with that in radial direction. According to this index the *Ailanthus* wood is of equal worth to walnut wood, which has head hardness 72 N.mm^{-2} and cross hardness 54 N.mm^{-2} (Enchev 1975). The compressive strength parallel to the direction of the *Ailanthus* fibers (55.83 N.mm^{-2}) was lower than that of oak (*Quercus*), 76.2 N.mm^{-2} (Enchev 1975). The shear strength parallel to the *Ailanthus* fibers (13.65 N.mm^{-2} in radial plane and 14.41 N.mm^{-2} in tangential plane) was almost equal of this of oak-tree: 13.8 N.mm^{-2}. The *Ailanthus* wood can split parallel to the direction of the fibers more difficult in tangential direction: 106.42 kN.m^{-1}, than in radial direction: 85.18 kN.m^{-1}. The modulus of linear deformation during static bending of *Ailanthus* timber (11,906 N.mm^{-2}) was almost equal to that of walnut (12,500 N.mm^{-2}), but it was considerably lower than that of the oak-tree (16,000 N.mm^{-2}) (Enchev 1975). We would like to stress the fact that both walnut and oak trees need much more years to reach the same diameter as the one studied in *Ailanthus* tree.

Table 2. Gluing strength of the timber of 11-years old *Ailanthus* tree.

No	Variant	Glue	n	Variation indexes in N.mm^{-2}					Destruction, %	
				Aver.	St.Dev.	Error	V, %	p, %	W	AF
1	P+P	Prefere 4114	36	5.01	1.01	0.17	20	3.3	100	-
2	P+P	Jowacol 107	36	4.85	1.15	0.19	24	3.9	90	10
3	A+ A	Prefere 4114	36	15.24	2.43	0.41	16	2.6	25	75
4	A+ A	Jowacol 107	36	13.13	2.83	0.47	22	3.6	10	90
5	A+ A	Jowacol 107	36	13.13	2.83	0.47	22	3.6	10	90
7	R+ R	Prefere 4114	36	16.93	3.08	0.51	18	3.0	20	80
8	R+ R	Jowacol 107	36	13.27	3.12	0.52	23	3.9	15	85

Symbols: P – *Paulovnia* timber; A – *Ailanthus* timber; Q – *Quercus* timber; A – *Robinia preudoacacia* timber; n – quantity of samples; W – destruction in wood; AF – adhesion destruction between wood and protective film.

The results displayed in Table 2 demonstrate that *Ailanthus* wood sticks very well with dispersion polyvinilacetate glues and with reactive urea-formaldehyde glues. The gluing strength of *Ailanthus* wood with the reactive glue Prefere 4114 was 15.24 N.mm^{-2} and with the dispersion glue Jowacol 107 was 13.13 N.mm^{-2}.

The *Ailanthus* wood can be varnished very well. Table 3 shows the average values of adhesion coatings formed with two-component polyurethane system (Pu-683/50+B-640) and the average values of coatings, formed with water-diluted acrylic varnishes (Aquis). The average values of adhesion of polyurethane (Pu) coatings ranged from 3.84 N.mm^{-2} to 6.37 N.mm^{-2}. The average values of adhesion of acrylic (AqA) coatings varied from 4.37 N.mm^{-2} to 9.75 N.mm^{-2}.

The comparative analyses proved that adhesion values depend on the roughness of wood surfaces over which the coatings are formed. When roughness of surface decreased, the cohesion of coatings also decreased, respectively. For example, series with index Pu 40 with roughness values 5.63 μm had adhesion 6.37±0.21

Table 3. Adhesion of coats on the timber of 11-years old *Ailanthus* tree.

Index	R_a μm	M_{dc} g.m^{-2}	Δ μm	n	Variation indexes in N.mm^{-2}					Destruction,%	
					Aver	St.D.	Error	V, %	p, %	WC	CM
Pu R	4.56	171	125	30	4.64	1.11	0.20	24	4.3	100	–
Pu 40	5.63	154	120	30	6.37	1.15	0.21	18	3.3	90	10
Pu 80	4.15	178	130	30	4.35	1.05	0.19	24	4.4	95	5
Pu 150	3.43	196	140	30	3.84	0.83	0.15	22	3.9	100	-
AqA R	4.35	268	210	30	8.76	2.20	0.40	22	4.1	75	25
AqA 40	5.75	266	210	30	9.75	2.06	0.38	19	3.5	95	5
AqA 80	4.05	283	215	30	8.32	2.18	0.39	18	4.7	100	–
AqA 150	3.25	267	215	30	4.37	1.12	0.20	25	4.6	90	10

Symbols: Pu – two-component polyurethane varnishes (Pu-683/50+B-640); AqA – Acrylic water dilute varnishes "Aquis"; R – planed down surface; 40 – surface, polished with sandpaper No 40; 80 – surface, polished with sandpaper No 80; 150 – surface, polished with sandpaper No 150; M_{dc} – weight of dry coat; δ –thickness of the dry coat; R_a – roughness of wood; WC – destruction between wood and coating; CM – destruction between the coating ant the metal punch.

N.mm^{-2} and series with index Pu 150 with roughness values 3.43 μm had adhesion 3.84 N.mm^{-2}. Similar tendency was observed with coatings formed with acrylic varnish, but these coatings had higher adhesion towards *Ailanthus* wood. For example, series with index AqA 40 with roughness values 5.75 μm had adhesion 9.75 ± 0.38 N.mm^{-2} and series with index AqA 150 with roughness values 3.25 μm had adhesion 4.37 N.mm^{-2}.

Conclusions

As a conclusion we can state that *Ailanthus altissima* is a fast growing species with high quality wood. The wood of trees grown under controlled conditions had very good physical and mechanical properties, some of which were comparable to the very expensive walnut wood. Therefore it can be used for manufacturing articles with different functions, including furniture. Based on our results we can recommend further studies directrd to establishment of experimental plantations in different growing conditions (climate and soils) and the possible uses of wood. They will confirm whether *Ailanthus altissima* can be successfully used as a fast growing species for quick production of valuable or energy source wood in Bulgaria. Yet, strict control in the plantation locations should be applied in order not to contaminate environmentally important protection areas, in which the invasive character of *Ailanthus altissima* may be a major threat.

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