www.biodicon.com Biological Diversity and Conservation

ISSN 1308-8084 Online; ISSN 1308-5301 Print 9/2 (S1) (2016) 58-63

Research article/Araştırma makalesi

Determination of physical and mechanical properties of beech (*Fagus sylvatica* L.) wood - utilization perspectives in Greece

Kamperidou VASILIKI [*1], Ioannis BARBOUTIS [1]

[1] Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood products Technology, 54124, Thessaloniki, Greece

Abstract

Beech wood is widely available across Europe, and one of the most important commercial hardwood species in European, as well as Greek, forestry. The scope of this research was to enlighten the production of Greek beech forests, the conditions of wood sawmills and the range of utilization possibilities of beech wood, by determining mechanical properties such as, bending strength, modulus of elasticity, radial and tangential hardness of beech wood and compare them with the respective values of previous researches results. Indicatively, the production of beech wood referring to lumber, materials for wood based panels and fuelwood in Greece the year of 2011 was 51.297, 7.472 and 219.653 m^3, respectively. Beech wood is classified as a medium density hardwood and it is a material of low price and low cost of machining. There is a big range of applications of this species with the most common application to be flooring, furniture, brushes, blocks, handles, veneers and woodenware. In Greece beech lumber was intended mainly for the construction of furniture as steamed wood in the apparent parts of the structure, as well as the upholstered furniture frames, boxes and pallets, as not steamed wood. Generally, the quality of the sawn beech logs in Greece is not quite satisfying, a fact proved by the low percentage of the produced beech lumber of the quality class A (approximately 10%). The financial crisis of the last years decreased the demand of wood and wood products in the market and as a result, many of the wood and furniture industries in Greece have been closed. Nowadays, there is not enough demand of beech round wood and annually large quantities of this material conclude to be used plainly as fuelwood, reducing the added value of beech wood. In a period of such an economical crisis as the current one, the use of domestic beech wood, which is a material of good price, of low machining cost, while parallel is characterized by satisfying mechanical and physical properties, could be increased and its utilization possibilities could be extended in a big range of applications, as solid wood or glued products.

Key words: beech, bending, hardness, mechanical strength, MOE

1. Introduction

Beech wood is a species that grows at an altitude of 500 m. up to 1800 m. In Greece beech is found mainly in the northern and central part of the mainland. It appears in the mountains of the northern border in north central and north eastern Greece, in the mountains of Eastern Central Greece, Holomontas in Halkidiki and the Mountain of Pindos. It dominates in the lowland, hilly and semi-mountainous zone and displays high competitiveness, forming extensive forests, pure or mixed with other hardwood and softwood species (Strid and Kit Tan, 1997).

The most famous tree of this species history was that of beech oracle of Dodoni from which the priests took the oracles interpreting rustling in combination with other sounds in their environment, although there is still a small doubt if that tree was indeed beech or oak tree. In some areas where the beech was not in abundance, prevailed to be called as “beech oak” or a kind of “oak” and generally, in the past there was a confusion over the name of beech and oak. Both 'oak' and 'beech' are 'fruit-bearing trees, offering food source for animals, so this confusion seems quite conceivable. Therefore, the Latin got the word “*Fagus*” (which word was used as the botanical name of genus of beech tree) from the Greek word “Φηγός” (phegos), with a ground sense of “edible” and is connected with the root of Greek word “Φάγειν” (phagein) meaning “to eat”.

[*] *Corresponding author* / Haberleşmeden sorumlu yazar: Tel.: +302310998845; Fax.: +302310998883; E-mail: vkamperi@for.auth.gr
 BioDiCon. 578-0716

It is classified as a medium density hardwood and thus, it is quite heavy (specific gravity of 0.75), hard, strong, odorless, of high resistance to impact strength forces and fine texture, available in large dimensions, which cannot usually be achieved with other species and additionally, is a material of low price and low cost of machining. Its heartwood does not normally differ from the sapwood part, but in many logs appears a coloration of the core, which is known as red heartwood of beech wood. Beech wood can be planed, coloured, polished and glued satisfactorily and bent extremely well even in very small radii. Also, the seeds of beech are rich in starch and oily substances, and are food for animals (pigs etc.). Important is also the use of its oil in the pharmaceutical as expectorant bacteriostatic, obtained by dry distillation of beech wood (Molnar et al., 2001).

Some of the most common applications are in flooring, furniture, brushes, blocks, handles, veneers, carvings and other woodworks. It is suitable for furniture construction that requires turning process. In Greece beech lumber was traditionally intended mainly for the construction of furniture, as the most basic species, in the obvious parts of the structure as steamed wood, as well as in the upholstered furniture frames, boxes and pallets, as not steamed wood, as the most basic wood species together with populous wood. It can be used also as fuel, since it produces excellent charcoal (Molnar et al., 2001).

The history of sawmills in Greece dates back to 1836 when it was founded the first saw which was working with water, which was the main method of sawing until 1950. The first modern mechanical mill, powered by steam, was founded by the University of Thessaloniki in Pertouli University Forest in 1936, followed by the establishing of four state sawmills in 1938 and 1939. In the decade of 1950 two more state sawmills were founded and since then the development of the sawn wood industry was great (Philippou, 1981a). Philippou (1981b) refer that two sawmills in Greece that produce beech wood recorded a recovery percentage of logs in lumber, relative to the logs diameter, 54.5% and 55.2%.

After a survey that took into account the market needs in Greece and the most common uses of sawn beech wood led the state sawmill of Litohoro to the production of lumber in certain combinations of dimensions: Depending on the length of the boards, they are classified into 3 categories:

- Category A: Length from 1.8 meters and over.
- Category B: Length from 1 meter to 1.7 meters.
- Category C: Length from 0.5 to 0.9 meter.

While depending on the existing defects, the lumber is classified into three quality classes: A, B and C. The defects that play decisive role in the classification of wood quality are: the size and number of knots, size of false heartwood, length and width of cracks of the edges, fissures, missing pieces from the processing and non-uniform texture (FSP, 1978). For the machining of timber numerous small sawmills were used, while in some of them there were also steaming equipment. These industries were using in great extent domestic wood and only a small amount of imported timber.

Generally, the quality of the sawn beech logs in Greece was not quite satisfying, a fact proved by the low percentage of the produced beech lumber of the quality class A, which ranged approximately to 10%. The quality classification of the sawn beech coming from sawmills in Greece is not based in official international standards, but each manufacturer establishes and follows their own criteria, which comply with the consumer's requirements and they show confidence on them (FSP, 1978). The state sawmill of Litohoro region (North Greece) was the largest one of the country in the production of sawn beech wood, recording up to 16.000 m^3 of round beech wood in the year of 1977 with a recovery percentage of this amounts in lumber up to 60%, of which the percentage of 9% was classified in A quality class, while the year of 1978 it processed 11037 m^3 of beech round wood with a recovery percentage of this amounts in lumber up to 64%, of which the 9% was again classified in A quality class (Prefecture of Pieria, Forest Department, 1979). The specific sawmill occupied 12 water reservoirs for the storage of round wood (Figure 1), for the rest of wood amounts the method of water spraying was used for its protection and preservation and also, this sawmill covered an area of 167,000 m^2. Generally, the region of Pieria Prefecture covers an area of 1548000 acres, while the 73996 of these acres are covered with beech species, which corresponds to 32.25% of the whole area and as it is mentioned before about the whole country, this species covers the largest area between the other indigenous species (Prefecture of Pieria, Forest Department, 1979). The 97% of produced lumber of excellent quality was destined to be steamed using the 12 steaming ovens of the plant and then stacked and left to dry naturally and gradually under the protection of shelters. Generally, steaming process makes beech wood to acquire an infrared staining (darker color) and additionally, makes it easier to be processed and properly dried. Additionally, steaming prepares wood to be processed for the construction of curved parts and contributes to the extinction of live microorganisms in wood (Voulgaridis and Tsoumis, 1982). Litohoro plant all these years was absorbing almost the entire round beech wood production amounts coming from the forest complexes that were exploited through direct labor by the Forest Service of Larissa, Aridaia and Pieria regions. The products of Litohoro plant were exclusively channeled in the market of Greece, they were known for their high and stable quality and those years these materials used to achieve very high prices, exceeding the production costs appreciably and leaving a high gain to the sawmill (FSP, 1978). Unfortunately, this sawmill was one of the numerous sawmills that stopped functioning due to the financial crisis almost five years ago.

In 1982 the actual number of sawmills in Greece was 642, of which 252 processed around 100-1000 m^3 of round timber and 303 were of 1000-5000 m^3 capacity in round timber, while all together processed a total of 567461 m^3

round wood based mainly on Greek species. Only the amount of 72872 m^3 was covered by imported round wood. Approximately the 40% of the Greek sawmills, referring to the number of them, as well as their production and total capacity of them, were located in Macedonia region, where the massive productive forests of the country are situated (Kavouras, 1985).

Figure 1. Pond-stored beech logs and steamed lumber in Litohoro sawmill

With the exception of a very small number of sawmills that have modern equipment, the Greek sawmills generally have old machinery, do not have furnaces for artificial drying of timber, facilities for natural drying and facilities for the protection of wood from the effects of weather conditions. Very few sawmills are equipped with facilities of steaming of timber (beech) or are equipped with facilities for further working out of timber (parquet, pallets, doors, furniture etc.) (Philippou, 1981a). Some of the main problems that wood industry in Greece faces are the lack of raw material, poor employment and exploitation of the machinery, high production costs, quite poor quality of products and weakness to promote and dispose the produced products (Philippou, 1981a). To the low quality of Greek sawn wood, contributed the poor quality of domestic raw materials, which was further deteriorated due to the poor harvesting and trafficking methods in the distances from the forest to the factory. As a result of that, the timber becomes available at lower prices in order to face the acute competition against the imported qualitative sawn timber (Philippou, 1981a). A large percentage of beech wood and its high value become lost in the circuit of activities of Logging-Processing-Use of wood, because of the poor organization and nonproper undertake of these activities, as well as non-adequate and proper utilizing of the currently established scientific knowledge and existing technology in the exploitation of wood.

The previous decades in Greece, an increase in the production of beech round wood and a decrease in fuel wood were observed, attributed partly to the gradual improvement of forest quality that had taken place (Philippou, 1981a). Despite this wood production increase, our country remained to a large extent a country based in imports, because our needs in wood could not be covered by the domestic production amounts. The financial crisis of the last years strongly decreased the demand of wood and wood products in the market and as a result many of the wood and furniture industries in Greece and especially the industries of larger capacity have been closed.

Therefore, nowadays there is not enough demand of beech round wood and annually large quantities of this material onclude to be used plainly as fuel wood, reducing the added value of beech wood. Nevertheless, in a period of an economical crisis such as the current one, the demand of low cost construction materials such as wood, is expected to be increased, compared to other building construction materials. Especially the use of domestic beech wood, which is a material of good price, that requires low cost to be machined, while at the same time is characterized by satisfying mechanical and physical properties, could be increased and its utilization possibilities could be extended in a big range of applications, as solid wood or glued products.

Instead of large wood industries that face more difficulties in their survival through this economical crisis, several smaller local enterprises could be established, in order to cover the needs of the market in qualitative wood of affordable price, especially in Greece which is a country deficit in wood quantities and base mainly on imports. Finally, as our study showed, the wood industries that adopted an orientation in commerce based on exports, managed to survive and maintain their profits and regular function inside these difficult economical conditions and this example could be characterized as one of the proper utilization tactics of beech wood in Greece. Indicatively, one of the wood industries of small size processes around 2000 m^3 of beech logs that have been previously qualitatively selected, presenting a lumber recovery percentage of 45% in qualitative (quality class A) lumber, the whole of which is destined for exports, and a percentage of 20% of B and C quality class lumber, which is channeled mainly in domestic market. The length of lumber pieces that this industry produces is between 2.10-3 m and the thickness mainly 25, 50 and 80 cm. He has been implementing exports since 8 years before and the only difficulty that his business faced came from the capital controls of the last months in the frame of this financial crisis in the country (Tzevelekos, 2015).

Several research works have been implemented so far on the mechanical properties of beech wood, some of whom are summarized in the following. Guntekin et al. (2014) investigated the bending properties of beech wood

(*Fagus orientalis*), while an attempt was made to predict them using stress - wave method and compare them with static bending tests. Skarvelis and Mantanis (2013) examined the physical and mechanical properties of two beech species (*Fagus sylvatica* L. and *Fagus orientalis* Lipsky) on samples originating from four different natural forests located in the central, northwest and northeast Greece and dry density, shrinkage (axial, radial, tangential), Janka hardness, static bending, longitudinal and cross-sectional compression, shear, cleavage and impact strength were investigated. Voulgaridis and Tsoumis (1982) determined mechanical properties of beech wood (*Fagus sylvatica* L.) such as Modulus of Rupture, Elasticity of wood, compression, hardness and toughness of wood, revealing the satisfying mechanical performance of this species. Lo Monaco et al. (2015) used two aged coppices of beech of Italian origin and analyzed several physical and mechanical properties, such as dry and basic density, radial, tangential and volumetric shrinkage, axial compression strength, static bending strength and Brinell hardness. Barboutis and Vasileiou (2013) studied the effects of the PVAc and PU adhesives and finger length (4.5 mm, 6.5 mm and 9.0 mm) on bending strength of finger-jointed steamed and unsteamed beech wood (*Fagus sylvatica*) and also examined some basic mechanical properties of solid beech wood.

2. Materials and methods

Beech wood (*Fagus sylvatica* L.) used in this research was obtained from a local wood industry in Pindos region (Central Greece) and it has been naturally desiccated for 8 months. The boards of beech wood were cut parallel to grain and were placed into a conditioned room at 20 ± 2°C temperature and 60 ± 5% relative humidity and were allowed there to attain a nominal equilibrium moisture content (EMC) of 9.32%. The mean density (oven-dry mass/volume, measured at 9.32% moisture content) of wood was found to be 0.722 g/cm^3.

These boards were cut in final cross section dimensions for the measurement of mechanical properties, according to the respective standards (Bending Strength-Modulus of Elasticity: ISO 3133:1975, Hardness (Janka): ISO 3350:1975). For each property test 10 replicate specimens were prepared, except for the hardness test where 15 replicate specimens were used. Specimens were weighed before the tests, dried in the oven at 103 ± 2°C for 24 hours and reweighed in order to estimate the mean moisture content of the specimens during the tests.

Bending 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. Tests of hardness in tangential and radial direction of wood specimens were also accomplished on an Amsler Universal Wood Testing machine, adjusting the respective ancillary equipment for this test on the machine.

3. Results

In Table 1, several physical and mechanical properties of beech wood were derived from the bibliography and this research work and are all presented, in order to be easily compared and measurement units were converted when necessary.

The results (Table 1) revealed that, the values of physical and mechanical properties of beech wood coming from the specific research are quite similar to those of the literature. More specifically, beech wood of Greek origin presented quite higher density, compared to other researches, which explains the quite higher values of the most mechanical properties. These small differences between the mechanical properties values of beech wood of different origins normally emerge and they could be attributed to each tree quality (genetic background), the environment where it develops, as well as the age and several other factors. Generally, this satisfying mechanical behavior of beech wood in the specific research increases even more the utilization possibilities of this species in Greece. These qualitative characteristics suggest more profitable use of this species than fuel wood and its mechanical properties make this material very attractive for industrial applications.

Table 1. Physical and mechanical properties of beech wood derived from this study (first column) and from the literature

Property	This experiments results	Voulgaridis and Tsoumis, 1982	Skarvelis and Mantanis, 2013	Lo Monaco et al. 2015	Cividini 1969	Barboutis and Vasileiou, 2013	Bektas et al. 2002	Pöhler et al.2006	Molnar et al. 2001
Basic density g/cm^3	0.722 (0.024)*	-	0.600-0.660	0.585-0.560	0.669	0.605 (0.052)	0.658-0.716	0.695	-
MOR (N/mm^2)	119.547 (13.671)	104.4 (9.4)	105.49 (16.6)	100.9-108.4	118	108.71 (5.77)	1204 kg cm-2	127	-
(MOE) (N/mm^2)	13419.826 (995.074)	(kp/m^2) 102732 (17199)	-	-	-	11163.8 (1246.6)			-
Compression parallel to grain (N/mm^2)	-	490 (52) (kp/m^2)	55.43 (4.5)	54.7-54.4	61	-	606 kgcm-2,		63.6
Hardness axial	-	(kp/m^2) 770 (117)	-	-	-	-	-		
Hardness radial	(kN) 5.945 (0.272)	(kp/m^2) 570 (93)	(N/mm^2) 48.54 (12.4)	-	-	-	-	(N/mm^2) Brinell 24.46	
Hardness tangential	(kN) 5.961 (0.313)	(kp/m^2) 502 (111)	(N/mm^2) 48.54 (12.4)	(N/mm^2) Brinel 29.8-27.7	-	-		(N/mm^2) Brinell 26.87	(N/mm^2) Brinell 25.1
Toughness (kpm/cm^3)	-	0.44 (0.19)	-	-	-	-	-		

*Numbers in parentheses represent the standard deviation

4. Conclusions and discussion

The scope of this research was to focus on the production of Greek beech forests, the conditions of wood sawmills and the range of utilization possibilities of beech wood, by determining mechanical properties such as, bending strength, modulus of elasticity, radial and tangential hardness of beech wood and compare them with the respective values of previous researches results. Beech wood (*Fagus* species) is a species widely available across Europe, one of the most important commercial hardwood species in European and also in the World (Ertekin et. al., 2015), as well as Greek forestry and is classified as a medium density hardwood of low price, low cost of machining and is characterized by satisfying mechanical and physical properties. In Greece, beech lumber was intended mainly for the construction of furniture as steamed wood in the apparent parts of the structure, as well as the upholstered furniture frames, boxes and pallets, as not steamed wood. Generally, the quality of the sawn beech logs in Greece is not quite satisfying, a fact proved by the low percentage of the produced beech lumber of the quality class A (approximately 10%).

The financial crisis of the last years decreased the demand of wood and wood products in the market and as a result, many of the wood and furniture industries in Greece have been closed. Nowadays, there is not enough demand of beech round wood and annually large quantities of this material conclude to be used plainly as fuelwood, reducing the added value of beech wood. Beech wood shows interesting qualitative characteristics, suggesting a more profitable use than fuelwood and its mechanical properties make this material theoretically very attractive for industrial applications.

The use of beech wood could be increased and its utilization possibilities could be extended in a big range of applications, as solid wood or glued products. Generally, in the future the wood industries should focus on wood exports, including solid wood or glued wood products. Especially the construction of glued products offers the opportunity to exploit material of low quality, as is the quality of the largest percentage of Greek timber, through the process of the defects removal from the lumber, contributing in that way in the construction of clear products of high added value..

References

Barboutis, I., Vasileiou, V. 2013. Strength of Finger-jointed Beech Wood (*Fagus sylvatica*) constructed with small finger lengths and bonded with PU and PVAC Adhesives. International Conference "Wood Science and Engineering in the Third Millennium" – ICWSE 2013

Bektas, I., Guler, G., Basturk, M.A. 2002. Principal Mechanical Properties of Eastern Beech Wood (*Fagus orientalis* Lipsky) Naturally Grown in Andırın Northeastern Mediterranean Region of Turkey Turk J Agric For 26 (2002) 147-154

Cividini, R. 1967. Study of the characteristics of parquet woods and their evaluation. Contributi scientifico pratici, Istituto Nazionale del legno, CNR, Roma, Italy, vol. 8, pp. 1-42.

Ertekin, M., Kırdar, E., Ayan, S. 2015. The effects of exposure, elevation and tree age on seed characteristics of *Fagus orientalis* Lipsky. *South-east Eur for* 6 (1): 15-23. DOI: http://dx.doi.org/10.15177/seefor.15-03

Forest Service of Pieria, 1978. State Wood Industry of Litohoro. Factsheet of 1978.

Guntekin, E., Ozkan, S., Yilmaz, T. 2014. Prediction of Bending Properties for Beech lumber using stress wave method. Maderas. Ciencia y tecnología 16(1): 93-98, 2014.

Kavouras, P. 1985. Forest Industries – A study of the strategy for the development of the Greek Forestry and Wood Science. Ministry of Agriculture, Forest Research Institute of Thessaloniki, Precursor Announcement of March-13-14-15 (1985).

Lo Monaco, A., Calienno, L., Pelosi, C., Balletti, F., Agresti, G., Picchio, R. 2015. Technical properties of beech wood from aged coppices in central Italy. iForest (2015) 8: 82-88.

Molnar, S., Nemeth, R., Feher, S., Tolvaj, L., Papp, G., Varga, F. 2001. Technical and technological properties of Hungarian beech wood consider the red heart. Wood Research 46 (1): 21-30.

MPREE (Ministry of Productive Reconstruction, Environment and Energy), 2014. Activities Report of Forest Service in Greece of the year of 2011. Athens, July 2014.

Prefecture of Pieria, Forest Department, 1979. The forested Pieria. Factsheet of Forest Department of Pieria. Katerini, March 1979.

Philippou, I. 1981a. Wood industry in Greece. Anatypo. Proceedings of International Symposium "Mechanization in forestry enjoyment." Thessaloniki 23-29 August 1981.

Philippou, I. 1981b. A study of sawing conditions on eight sawmills in Greece. Scientific annals of the school of Agriculture and Forestry. Vol.24, No.3.

Pohler, E., Klingner, R., Kunniger, T., 2006. Beech (*Fagus sylvatica* L.) - Technological properties, adhesion behaviour and colour stability with and without coatings of the red heartwood. Ann. For. Sci. 63 (2006) 129–137

Skarvelis, M., Mantanis, G. I. 2013. Physical and Mechanical properties of Beech Wood harvested in the Greek public forests. Wood Research, 58 (1).

Strid, A., Kit Tan, 1997. Flora Hellenica. Vol.1, Koeltz, Konigstein.

Tzevelekos, A. E. 2015. Tzevelekos A.E. – A standard unit in wood processing. (http://www.tzevelekossa.gr/index.php?option=com_content&view=article&id=9&Itemid=)

Voulgaridis, E., Tsoumis, G. 1982. Effect of steaming on the properties of Beech wood. Scientific annals of the school of Forestry and Natural Environment. Vol.KE, No.5.

(Received for publication 28 August 2015; The date of publication 15 August 2016)