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PHYSICAL AND MECHANICAL PROPERTIES OF BEECH WOOD HARVESTED IN THE GREEK PUBLIC FORESTS

Michalis Skarvelis, George I. Mantanis
Technological Education Institute of Larissa, Department of Wood and Furniture Design and Technology, Laboratory of Wood Technology
Karditsa, Greece

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ABSTRACT

This work reports on the properties of beech wood, one of the most important hardwood species, harvested in the Greek public forests. The physical and mechanical properties of two beech species, namely *Fagus sylvatica* L. and *Fagus orientalis* Lipsky, were investigated on samples originating from four different natural forests located in the central, northwest and northeast Greece (Larisa, Metsovo, Kastoria, Xanthi). The properties studied were dry density, shrinkage (axial, radial, tangential), Janka hardness, static bending, longitudinal and cross-sectional compression, shear, cleavage and impact strength. Metsovo's originating *Fagus sylvatica* wood showed the highest dry density (0.66 $g.cm^{-3}$), while beech wood from Xanthi (*Fagus orientalis*) exhibited the lowest one (0.60 $g.cm^{-3}$). The mean width of annual rings varied from 2.03 to 2.28 mm, noticeably not in accord with the respective densities. Radial shrinkage was found to be 5.46 % on the average; mean tangential and volumetric shrinkage was 9.93 % and 15.08 %, respectively. In regard to the mechanical properties, mean values for static bending, Janka hardness, compression parallel to the grain, compression perpendicular to the grain, shear, impact bending and cleavage of beech wood were found to be 105.49, 48.54, 55.43, 11.96, 14.85, 784.35 and 26.45 $N.mm^{-2}$, respectively.

KEYWORDS: Beech, wood properties, *Fagus sylvatica*, *Fagus orientalis*, density, shrinkage, mechanical properties, Greek public forests.

INTRODUCTION

Beech forests indigenously grow in central Europe, in the Balkan peninsula, from Greece and Bulgaria up to the Caucasus along the Black sea region and Turkey. As a matter of fact, beech wood is one of the most important commercial hardwood species in southeastern Europe.

Beech forests in Greece mainly grow at high altitudes on mountains; from mountain

Oxia (central Greece) up to the northern boarders. Furthermore, beech wood has an economic importance for Greece along with fir, pine and oak species (Fig. 1). Beech is utilised mainly as round wood and fuel wood (Fig. 2). Overall harvest of beech wood is comparable to those of pine and oak forests, that is, ca. 300.000 m^3 per year; 75 % of that comes from the public forests.

In the Greek market, beech wood is utilised as sawn timber in furniture production, but a large amount is also used for fuel wood, boxes, top benches, pallets, toys and wood-based panels (particleboard, fibreboard). In the past, beech wood used to be treated with oil preservatives. In overall, beech wood is classified as a medium-high density hardwood. It has a high resistance to shock and is highly suitable for steam bending (Tsoumis 1983). It dries fairly fast using various drying methods and schedules, although it is prone to distortions, splitting and colour changes during drying (Skarvelis et al. 1998, Allegretti et al. 2009). Most of beech sawn timber produced in Greece used to be steamed to make its colour uniform. Nowadays this is not so common, as fashion preferences have changed and wood prices are at a low level.

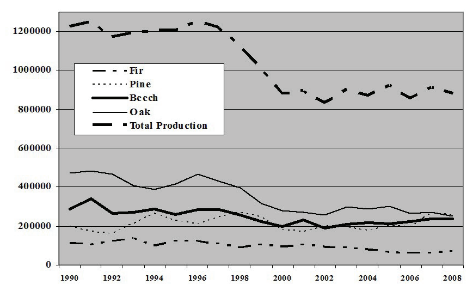

Fig. 1: Total production of main wood species from the Greek public forests per year, in m^3 (Greek Ministry of Agriculture 2009).

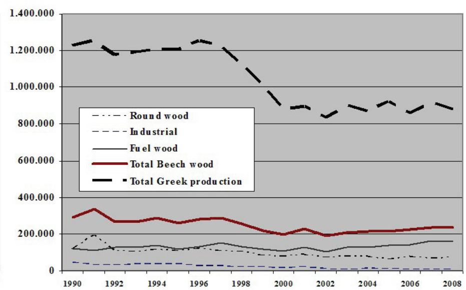

Fig. 2: Production of beech wood (round wood, industrial, fuel wood) from the Greek public forests per year, in m^3 (Greek Ministry of Agriculture 2009).

Nevertheless, no sufficient data are reported concerning the differences of beech wood in relation to their origin. Consequently, the aim of this work was to determine the principal physical and mechanical properties of beech wood harvested from four different public Greek forests and also to compare them with those of beech species of other origins.

MATERIAL AND METHODS

Wood samples were taken from public beech forests in the districts of Larisa, Metsovo, Kastoria and Xanthi, Greece (Fig. 3). The wood material from Xanthi's area belongs to species *Fagus orientalis* Lipsky, while the rest come from the species *Fagus sylvatica* L.

In each of these forest areas, five mature trees were randomly selected and cut. Each tree was at least 300 m away from the next tree cut. From each tree, a log approx. 90 cm in length was taken, just over the breast height. Thereafter a central plank was sawn from which thinner specimens, with cross sections of 20 x 20 mm, were produced. In Tab. 1 and 2, the exact dimensions of the specimens prepared are given as well as the standard methods used for the determination of physical and mechanical properties.

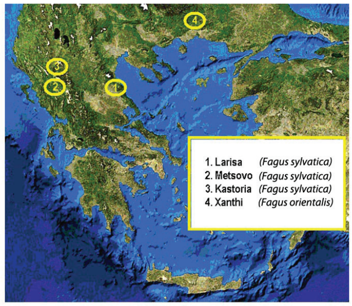

Fig. 3: Forest areas in Greece where from beech wood samples were collected.

For dry density, ISO 3131 1975 standard was applied. Shrinkage of wood was evaluated as total shrinkage, i.e. from the fibre saturation point to 0 % moisture content. Prior to testing, all wood specimens were conditioned in normal climatic conditions (temperature 20±2°C, relative humidity 65±5 %) for eight weeks according to standard EN 408 (EN 408 2003). Mechanical properties were tested using British and ISO Standards for small clear specimens (BS 373 1957, ISO 3132 1975, ISO 3133 1975, ISO 3348 1975, ISO 3350 1975, ISO 3347 1976, ISO 3787 1976).

RESULTS AND DISCUSSION

The results of the physical and mechanical properties of beech wood, namely *Fagus sylvatica* L. and *Fagus orientalis* Lipsky originating from Larisa, Metsovo, Kastoria and Xanthi public forest areas in Greece are presented in Tab. 1 and 2.

According to Tab. 1, there has been a slight variation in the mean width of annual rings, varying from 2.03 (Kastoria's beech origin) to 2.28 mm (Larisa's beech origin). Different growth rate is mainly owed to different site conditions in each area (climate, soil conditions, water) but also due to the individual genetic characteristics of the species itself; however, wood density is rather high in Metsovo's beech origin (0.66 $g.cm^{-3}$) and low in Xanthi's beech origin (0.60 $g.cm^{-3}$).

The mean value of dry density of all beech origins was found to be approx. 0.64 $g.cm^{-3}$. This value is similar to what Voulgaridis (1987) refers to for steamed beech wood (0.633 $g.cm^{-3}$). The same author refers to a value of 0.744 $g.cm^{-3}$ for non-steamed wood of Greek beech without mentioning the origin of the species and its position inside the tree. For beech wood (*F. sylvatica*) of French origin, a dry density of 0.71 $g.cm^{-3}$ is reported at 12 % MC level (CIRAD 2009). Pöhler et al. (2006) refer to a density of 0.695 $g.cm^{-3}$ for European beech (*F. sylvatica*), while Tsoumis (1983) reports a dry density of 0.70 and 0.74 $g.cm^{-3}$ at 12-15 % MC level for the same species.

As far as it concerns shrinkage properties, small differences were found to exist among the three origins of *F. sylvatica* (Larisa, Metsovo and Kastoria) and a small difference between them and that of *F. orientalis* (origin of Xanthi) which showed lower shrinkage values.

Mean values of radial shrinkage (5.46 %) of all origins were found to be lower than those reported by Voulgaridis (1987) for natural Greek beech wood (6.14 %), and higher than those of steamed Greek beech wood (5.07 %); however, the values obtained in this work are very close to the value of 5.7 % reported for French beech (CIRAD 2009) and those of 5.8 and 5.33 % referred by Tsoumis (1983) and Yilgor et al. (2001), respectively.

Tab. 1: Physical properties of beech wood investigated in this work.

Origin	**Mean width of annual rings (mm)**	**Density (dry) ($g.cm^{-3}$)**	**Longitudinal shrinkage**	**Radial shrinkage**	**Tangential shrinkage**	**Volumetric shrinkage**
			(%)			
Specimen dimensions	---------------->	**20 x 20 x 30 mm**				
Larisa	2.28	0.64 (54)1	0.36 (56)	5.51 (53)	10.04 (53)	15.24 (54)
Metsovo	2.06	0.66 (61)	0.26 (57)	5.81 (60)	10.06 (62)	15.55 (62)
Kastoria	2.03	0.64 (60)	0.29 (59)	5.60 (60)	10.04 (60)	15.33 (60)
Xanthi	2.25	0.60 (54)	0.33 (61)	4.92 (54)	9.56 (54)	14.21 (51)
Mean value	2.15	0.64	0.31	5.46	9.93	15.08
Standard deviation	0.12	0.03	0.04	0.38	0.24	0.59
Confidence interval at 99 % level[2]	0.10	0.02	0.04	0.31	0.20	0.49

[1]: In parentheses, the number of used specimens is given.

[2]: Confidence interval estimation based on the average values of the 4 beech origins.

As regards tangential shrinkage, similar values were observed (10.04-10.06 %) for all *F. sylvatica* origins and a little lower value (9.56 %) for *F. orientalis*. The mean tangential shrinkage (9.93 %) of all origins was quite lower than the mean value reported by Voulgaridis (1987) for natural Greek beech wood (13.89 %). This mean value was also lower than the values of 11.8 and 11.4 % reported by Tsoumis (1983) and Yilgor et al. (2001), respectively, for *F. sylvatica* wood. The mean volumetric shrinkage was found to be approx. 15.08 %.

In Tab. 2 the mechanical properties of the beech wood origins investigated are shown. Kastoria's beech wood material appeared to have higher mechanical properties in comparison to the other origins particularly in hardness and compression strength parallel and perpendicular to grain; however it showed the lowest performance in shear strength. Metsovo's originating beech wood exhibited the highest properties in shear and impact bending, but also significantly inferior static bending strength, while beech wood samples from Larisa's forests showed to have very high static bending properties.

Xanthi's originating wood material (*F. orientalis*) appeared to have the lowest mechanical properties of all origins.

Bektaş et al. (2002) in their work have reported *F. orientalis* wood property values of 120.4, 60.6, 850 $N.mm^{-2}$ for static bending, axial compression, impact bending, respectively; these values are quite higher than those found for Xanthi's beech wood material in this work.

The mean value for static bending strength (105.49 $N.mm^{-2}$) found in this work is very close with the value of 104.4 $N.mm^{-2}$ reported by Tsoumis (1983); nevertheless it is quite lower than the respective value of 111.0 $N.mm^{-2}$ for French beech origin (CIRAD 2009) and that of 127 $N.mm^{-2}$ for Central European beech origin (Pöhler et al. 2006). Similarly, Yilgor et al. (2001) have reported a static bending value of 104 $N.mm^{-2}$ for beech wood.

Tab. 2: Mechanical properties of beech wood investigated in this work.

Origin	Static bending	Hardness	Compression parallel to the grain	Compression perpendicular to the grain	Shear	Impact bending	Cleavage
	(N.mm^{-2})						
Standard used	(ISO 3133)	(ISO 3350, Janka test)	(ISO 8375, EN 408)	(ISO 8375)	(ISO 3347)	(ISO 3348)	(BS 5820 Monin test)
Specimen dimensions	20x20x300 mm	20x20x60 mm			20x20x20 mm	20x20x300 mm	20x20x45 mm
Larisa	118.25 (50)1	47.82 (51)	56.62 (52)	10.94 (48)	16.12 (51)	708.08 (51)	26.84 (53)
Metsovo	81.50 (60)	41.34 (63)	56.32 (67)	14.45 (67)	16.30 (68)	892.40 (48)	25.51 (64)
Kastoria	115.04 (62)	66.30 (62)	59.68 (62)	14.61 (58)	12.16 (63)	832.65 (57)	26.33 (58)
Xanthi	107.19 (55)	38.69 (55)	49.11 (55)	7.85 (54)	14.80 (56)	704.28 (53)	27.11 (54)
Mean value	105.49	48.54	55.43	11.96	14.84	784.35	26.45
Std. deviation	16.6	12.4	4.5	3.2	1.9	93.5	0.7
Confid. interval. at 99 % level[2]	13.701	10.238	3.682	2.650	1.572	76.911	0.580

[1]: In parentheses, the number of used specimens is given.

[2]: Confidence interval estimation based on the average values of the 4 beech origins.

Very similar or slightly higher were found to be the mean values for properties like hardness (48.54 N.mm^{-2}), axial compression (55.43 N.mm^{-2}), compression perpendicular to grain (11.96 N.mm^{-2}), shear strength (14.84 N.mm^{-2}) and impact bending (784.35 N.mm^{-2}), as compared to those cited by Tsoumis (1983) for *Fagus sylvatica* wood. For axial compression, Yilgor et al. (2001) have reported a value of 54.20 N.mm^{-2} for beech wood, which is very similar to that found in this work.

In addition, the correlation coefficients (Pearson correlation factors) of dry density with the mechanical properties, i.e. static bending, compression, hardness etc. was analysed, and the results are shown in Tab. 3. From these analyses, the correlations between compression strength parallel to grain and density were very weak, while hardness seemed to be somehow better correlated with density compared to the rest of the mechanical properties; the correlation coefficient (R^2) reached the value of 0.725 (Metsovo's beech origin) in linear regressions.

From the statistical analysis in each origin (Tab. 3), it is concluded that beech wood originating from Larisa's forests showed to have the largest standard deviations and intervals both in physical and mechanical properties.

This indicates that this origin obviously is the least homogeneous wood material in comparison with the other Greek beech samples.

Tab. 3: Statistical analysis of data (standard deviation, confidence interval at confidence level 99 % and correlation of wood properties in each origin to the relevant dry density).

Origin		Static bending	Hardness	Compr. parallel to the grain	Compr. perpend. to the grain	Shear	Impact bending	Cleavage	Longitu-dinal shrink.	Radial shrink.	Tang. shrink.	Volum. shrinkage
Larisa	St. Dev.	14.744	5.752	7.488	3.210	1.654	29.365	5.237	1.192	1.423	0.218	1.813
	Conf. Int. at 99 %	5.318	2.075	2.674	1.181	0.596	10.592	1.853	0.422	0.503	0.086	0.641
	Corr. to density	0.419	0.594	0.450	0.318	0.319	0.099	0.095	0.433	0.166	0.133	0.425
Metsovo	St. Dev.	8.875	6.041	6.511	2.056	1.442	29.431	3.744	0.524	1.012	0.275	1.182
	Conf. Int. at 99 %	2.951	1.961	2.049	0.647	0.450	10.942	1.205	0.179	0.337	0.090	0.387
	Corr. to density	0.409	0.725	0.576	0.620	0.720	0.317	0.511	0.004	0.573	0.049	0.511
Kastoria	St. Dev.	14.712	5.471	5.558	2.161	1.386	22.923	4.561	0.900	0.873	0.259	1.411
	Conf. Int. at 99 %	4.813	1.790	1.818	0.731	0.450	w7.640	1.543	0.299	0.290	0.086	0.509
	Corr. to density	0.532	0.675	0.393	0.323	0.535	0.489	0.003	0.418	0.497	0.199	0.552
Xanthi	St. Dev.	12.965	6.987	7.637	1.145	1.690	17.303	5.151	0.739	1.200	0.316	1.579
	Conf. Int. at 99 %	4.503	2.427	2.653	0.401	0.582	6.122	1.789	0.244	0.421	0.111	0.570
	Corr. to density	0.632	0.680	0.536	0.809	0.660	0.536	0.577	0.735	0.682	0.271	0.839

CONCLUSIONS

In this study, the physical and mechanical properties of beech wood harvested in Greece were investigated on samples originating from four different natural public forests (Larisa, Metsovo, Kastoria, Xanthi - Greece). The properties studied were dry density, shrinkage (axial, radial, tangential), Janka hardness, static bending, longitudinal and cross-sectional compression, shear, cleavage and impact strength. The physical and mechanical properties of beech wood species like *Fagus sylvatica* and *Fagus orientalis* were compared with each other as well as with findings from other studies carried out on the same species elsewhere.

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Michalis Skarvelis, George I. Mantanis
Technological Education Institute of Larissa
Department of Wood and Furniture Design and Technology
Laboratory of Wood Technology
Gr-431 00 Karditsa
Greece
Phone: +30 6947 300585
Corresponding author: mantanis@teilar.gr