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İLKER USTA

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Comparative Study of Wood Density by Specific Amount of Void Volume (Porosity)

İlker USTA*
Hacettepe University, Department of Wood Products Industrial Engineering, 06532 Ankara - TURKEY

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Abstract: Various methods were progressively investigated to determine wood density within the most reliable void volume (porosity) values. Three softwood species of Bornmulleriana fir (*Abies bornmulleriana* Mattf.), Eastern spruce (*Picea orientalis* Lipsky), and Scots pine (*Pinus sylvestris* L.) grown indigenously in Turkey were selected to obtain a comparison among the green volume (GV), oven dry (OD) and maximum moisture content (MMC) methods. Volume definition had a great effect on density, which tended to vary significantly between and also within species caused by differences in the ratio of cell wall to air spaces. Accordingly: (a) GV might not give more accurate density figures than the others, as this method varies depending on the moisture content, which may be time-of-year dependent; (b) OD may also give unreliable results if the experimental blocks are not dried properly due to the direct reflection of the amount of space occupied by water; (c) MMC gives the most reliable results as the ranges of density are very close to each other along the same stake, and, it can thus be recommended for common use on account of its accuracy.

Key Words: Wood density, Porosity, Moisture content, Green volume method, Oven dry method, Maximum moisture content method

Mutlak Boşluk Hacmi (Porosite) Bağlamında Farklı Özgül Ağırlık Belirleme Yöntemlerinin Karşılaştırmalı Araştırması

Özet: Bu çalışmada, en doğru boşluk hacmi (porosite) değerine bağlı ağaç malzemenin gerçek özgül ağırlığını elde etmek için farklı belirleme yöntemleri göreceli olarak etkin bir şekilde araştırılmıştır. Bu amaçla, Türkiye`de doğal olarak yetişen iğne yapraklı ağaç türlerinden Uludağ göknarı (*Abies bornmulleriana* Mattf.), Doğu ladini (*Picea orientalis* Lipsky), ve Sarıçam (*Pinus sylvestris* L.) özellikle seçilerek yaş hacim (GV), fırın kurusu (OD) ve en yüksek rutubet miktarı (MMC) yöntemlerinin karşılaştırması yapılmıştır. Mevcut hücre çeperi miktarının hava boşluğuna oranının ağaç türleri arasında ve her bir türün kendi içerisinde belirgin olarak farklılıklar göstermesi nedeniyle hacim tanımlamasının özgül ağırlığa oldukça fazla etkisinin bulunduğu belirlenmiştir. Deneysel bulgular doğrultusunda aşağıdaki genel sonuçlara ulaşılmıştır: (a) mevsime bağlı rutubet miktarının etkisi nedeniyle diğer iki yönteme kıyasla GV yöntemi özgül ağırlık sonuçlarını tutarlı olarak veremeyecektir, (b) ağaç malzemenin tamamen kurutulamaması halinde boşlukların içerisinde bulunan su miktarının bir yansıması olarak OD yöntemi de tutarsız sonuçlar verebilecektir, (c) aynı parçanın hemen her yerinde özgül ağırlık sonuçlarının eşdeş bulunması ve ortalamadan uzaklıkların oldukça küçük olması dolayısıyla MMC yöntemi en tutarlı özgül ağırlık sonuçlarını verecektir. Bu nedenle, ağaç malzemenin gerçek özgül ağırlık değerinin belirlenmesi için MMC yönteminin yaygın olarak kullanılması önerilebilir.

Anahtar Sözcükler: Özgül ağırlık, Porosite, Rutubet miktarı, Yaş hacim yöntemi, Fırın kurusu yöntemi, En yüksek rutubet miktarı yöntemi

Introduction

Density is a measure of the quantity of cell wall material contained in a specific volume of a piece of wood, is an index of void volume (Hughes, 1967), is calculated as the ratio of dry weight of wood to volume and is measured in units such as kilograms per cubic meter. On the other hand, void volume is the amount of empty/air spaces comprised by cell cavities and intercellular spaces in a given volume of wood. Siau thus (1971) defines porosity as the fractional void volume of wood.

As the amount of moisture in wood influences density determinations by the amount of voids in relation to the cell wall materials (Bamber and Burley, 1983), the amount of moisture in wood must be indicated or specified with a density figure (Siau, 1984), and wood density is thus usually expressed in one of the following ways: green (with the same moisture content as in the

* Correspondence to: iusta@hacettepe.edu.tr

living tree), oven-dry (after heating in an oven at 103 ºC until constant mass is achieved), or air-dry (at equilibrium with ambient conditions or other specified conditions) (Skaar, 1972). Due to the expression of density as in one of the conditions mentioned above, density values may vary within the same specimens due to differences volume determination wood samples (Denne, 1979; Desch and Dinwoodie, 1996).

In earlier studies (Weatherwax and Tarkow, 1968; Harris, 1969; Olesen, 1971; 1977; Harvald and Olesen, 1987) considerable efforts were devoted to the improvement of methods of isolation and fractionation of the moisture content in wood voids for the determination of specific wood density with the actual amount of void volume (porosity). In this study, therefore, different methods were compared for defining the specific porosity of widely used Turkish softwood species.

Materials and Methods

Three softwood species of Bornmulleriana fir (*Abies bornmulleriana* Mattf.), Eastern spruce (*Picea orientalis* Lipsky), and Scots pine (*Pinus sylvestris* L.) grown indigenously in Turkey were specially selected to obtain a comparison of the various methods of determining density to observe specific porosity.

Collection of Samples: One defect-free sapwood stake from each of the three species was produced (750 mm in longitudinal length x 25 mm in tangential width x 25 mm in radial width) by silk cutting. Actual moisture content of each stake was then nominated to approximately 12% by a conditioning process in a constant temperature and humidity room set at 20 ºC and 65% relative humidity. Each stake was then clearly cut along its length into 72 blocks of 5 mm in longitudinal length, and 12 subgroups were created by taking six consecutive blocks end on to one another as they were located before being cut along the stakes in question (Figure 1).

Definition of cell wall material (K) and void volume (porosity, P): Wood is a cellular/porous material (Kollmann and Cote, 1968) composed of cell wall substances and cavities containing air and extractives (Tsoumis, 1991). Without cavities and intercellular spaces the relative density (d), used here synonymously with specific gravity, of the cell wall materials is practically constant for all timbers with a specific gravity of 1.53 gcm^{-3} on an oven dry mass and volume basis, and the cell wall materials are therefore one-and-half times heavier than water (Dinwoodie, 1981). The specific gravity of 1.53 gcm^{-3} is an ideal physical value for a lignified cellulosic cell wall which is completely non-porous. However, wood is not comprised of 100% cell wall material because it contains air pockets in the cell lumens. Therefore, as described by Kellog and Wangaard (1969), the amount of cell wall material is measured as a function of wood density (K = d/1.53), and void volume is defined in relation to the amount of actual cell wall material (P = 1-K).

Determination of density (d = Mg/Vg) by the green volume (GV) method: This method is simpler the oven dry (OD) and maximum moisture content (MMC) methods since the measurement of volume and mass is easy. The green volume (Vg) is dimensionally measured with a micrometer and the mass at green state (Mg) is measured on a balance accurate to four decimal places without any oven drying procedure because density is calculated at the same moisture content as in the living tree, so green volume (Vg) and green mass (Mg) can be measured (Kollmann and Cote, 1968).

Determination of density (d = Mo/Vg) by the oven dry (OD) method: The green volume (Vg) is directly

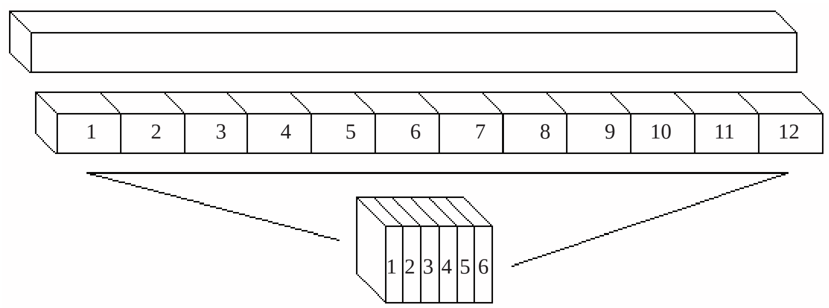

Figure 1. Collection and preparation of the experimental blocks from each stake.

dimensionally measured using a micrometer, likewise with the green volume method. Oven dry mass (Mo in this method) is measured after oven drying of the wood at 103 ± 2 ºC to a constant mass within a repeat weighing time of 24 h (Panshin and de Zeeuw, 1980).

Determination of density (d = Mo/[(Mo/G) + (Ms-Mo)]) by the maximum moisture content (MMC) method: Determination the green volume in this method is by recourse to the known consistent value for the specific gravity of the cell wall substance (G), which is taken to be 1.53 gcm^{-3} (Smith, 1954), and hence, before measuring the oven dried mass (Mo), the wood must fully be saturated (Ms) by deionised water to measure the real volume according to the Archimedes principle, which states that a body immersed in a fluid experiences an upthrust equal to the weight of the fluid displaced. Thus a completely saturated wood block displaces an amount of water equal to its own volume (Olesen, 1971).

Preparation of the Samples: After the samples had been collected, loose fibres were removed with a razor blade, and in order to obtain the actual green volume (Vg) and green mass (Mg), each experimental block was dimensionally measured with a micrometer and weighed on a scale. Data observed at this stage were noted for use in the determination of density by the GV method. All the blocks were then placed into a vacuum desiccator for saturation by deionised water (3750 cc.), which contained a fungicide of 25 ml. A vacuum impregnation procedure was then continuously performed for 10 days (i: application of -80 kPa (600 mmHg) vacuum for 12 h, ii: the desiccator was kept closed for 12 h, iii: activation of the application of the former vacuum stage). After completing the soaking time under vacuum, the experimental blocks were assumed to be fully saturated, and were then individually weighed in a beaker of deionised water to determine the saturated mass (Ms). Subsequently, the blocks were dried in an oven at 103 ± 2 ºC for 24 h. After drying, the blocks were cooled in a desiccator charged with granulated silica and reweighed to determine the oven dry mass (Mo). Mo data were first taken for density determination by the OD method, and then used in the MMC method with Ms to determine the wood density.

Statistical Analysis: Tukey pairwise comparison tests were performed to identify significant differences between treatment means after having performed a one-way analysis of variance using the statistical package MINITAB, version 10.51 (Minitab Inc. Minitab for Windows, 1995). Pairwise differences of density between the determination methods were compared to each other at $P \leq 0.05$ level in all species.

Results and Discussion

Mean density and its ranges for each determination method are shown in the Table, where the percentage of

Table. Mean density and its ranges for each determination method for all of the three softwood species, including the percentage of cell wall (K), the percentage of cell void (void volume as porosity, P) and its ranges.

Species	Methods	Density (kg m^{-3})			K (%)	P (%)	
		mean	SD	range	mean	mean	range
Fir	GV	478 a	7.7	466 - 492	32	68	67.2 - 68.9
	OD	421 b	8.1	405 - 433	28	72	71.2 - 73.0
	MMC	409 c	5.1	399 - 417	27	73	72.2 - 73.4
Spruce	GV	529 a	15.6	488 - 546	35	65	63.6 - 67.4
	OD	458 b	8.5	450 - 479	31	69	68.0 - 70.0
	MMC	428 c	5.2	415 - 435	29	71	70.9 - 72.3
Pine	GV	556 a	10.9	540 - 579	37	63	61.4 - 63.9
	OD	491 b	14.9	463 - 526	33	67	64.9 - 69.1
	MMC	469 c	12.8	444 - 498	31	69	66.8 - 70.4

GV: green volume method, OD: oven dry method, MMC: maximum moisture content method.
Means shown here are of data from 72 experimental blocks (12 sub-groups by six consecutive blocks per determination method) in each trial species.
SD: standard deviations.
Values within the same group followed by dissimilar letters are significantly different to each other using the Tukey comparison test at $P < 0.05$ level.

cell wall (K) and the percentage of void volume as porosity (P) are also given for each technique among the three softwood species. Furthermore, the variations of wood density in relation to the percentage of porosity are graphically illustrated in Figure 2 for comparison of the determination methods by means of all six blocks on the point of 12 locations along the experimental stakes from the species considered.

Wood density is manifested by a corresponding increase in the amount of water in the cell voids of the given volume since the porous space is occupied by water, which is a major factor in increase in wood density (Zobel and van Bujitenen, 1980). This theoretical explanation fits the findings of the present study. The experimental results given in the Table show that the determination of the void volume influenced wood density. For instance, the green volume (GV) method created quite high density values in all of the three species and had the greatest amount of cell wall material and the lowest amount of voids (porosity) compared to the other two methods.

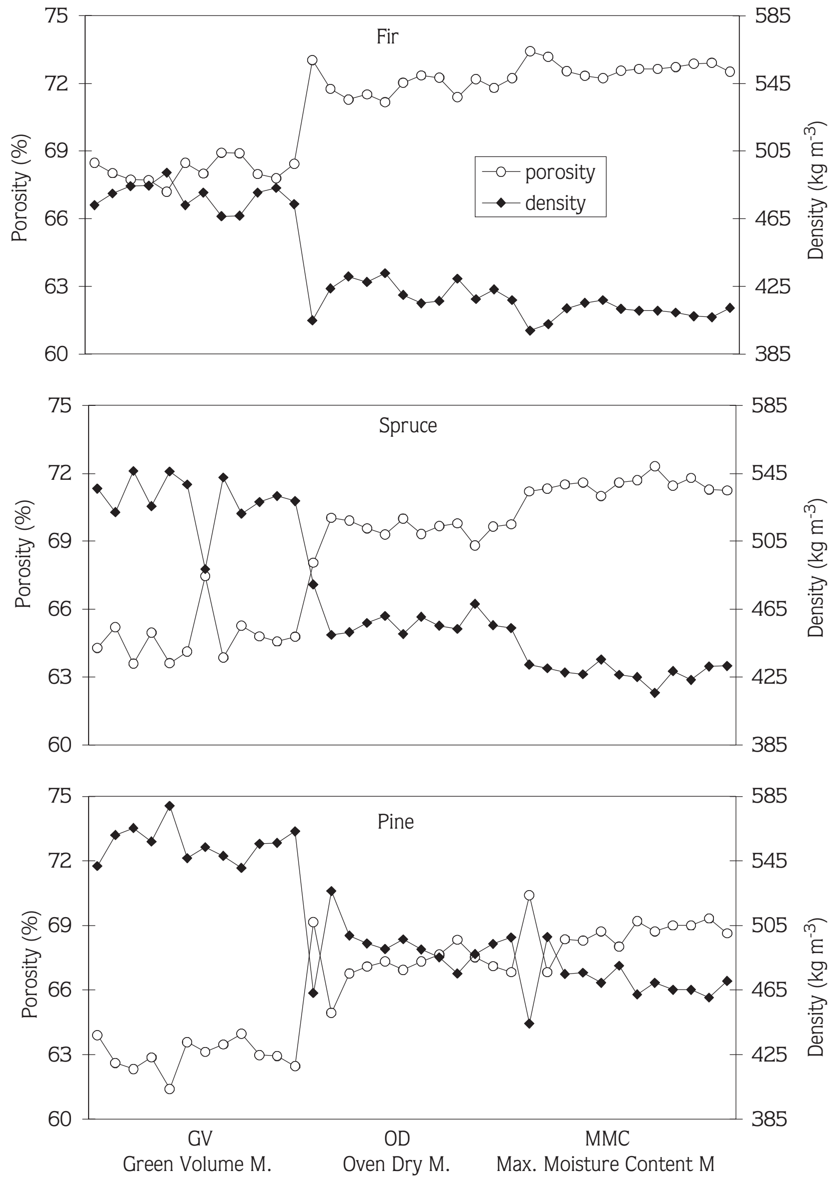

Figure 2. Variations of porosity and wood density determined by various methods in the softwood species among the 12 locations of the experimental stakes.

Conversely, the density values were close to each other in the oven dry (OD) and maximum moisture content (MMC) methods for the wood species tested. However, density values were significantly low in the MMC method, with the highest amount of porosity and the lowest amount of cell wall material.

According to Polge (1966), differences in density and void volume (porosity) may arise simply from differences in the anatomy of the wood modified by the effect of extractives, and, as described by Fries (1986) and Mitchell and Denne (1997), they may also derive from anatomical differences, such as in cell types and quantitative distribution, thickness of cell walls and size of cell cavities through the wood. Importantly, the cell wall substance adsorbs and desorbs moisture to and from the environment because wood is a hygroscopic material. One consequence of this is that the cell wall shrinks and swells, and the relative proportions of cell wall substance and pore space thus vary greatly (Olesen, 1977). Therefore, some variation in values was found, as expected, in density, which tended to vary significantly between and also within species caused by differences in the ratio of cell wall to air spaces (Figure 2).

Conclusions

By using the above observations it can be concluded that reliable results for wood density depend on the expression of wood volume, and some points may be clarified in detail for each determination method.

Green volume (GV) method: This method will vary depending on the moisture content, which may be time-of dependent. Therefore, this method might not give more accurate figures than the oven dry (OD) and maximum moisture content (MMC) methods. In addition, the volume values may not be properly determined if the shape of the experimental blocks is not of the stereometric dimensions necessary for the proper determination of the wood volume.

Oven dry (OD) method: In this method, the volume of experimental blocks is first measured dimensionally, then all the blocks are dried in an oven to obtain a constant mass of the samples. As the oven dry density of any wood species is a direct reflection of the amount of space occupied by the wood tissue (Walker, 1993), this method may give unreliable results if the experimental blocks are not dried properly.

Maximum moisture content (MMC) method: According to Olesen (1971), the maximum moisture content method (the weight after drying until constant mass divided by the green volume) gives less variation provided that the experimental blocks are properly saturated by the deionised water. This has been observed in the present study, i.e. the ranges in density (and also in porosity) were very close to each other along the experimental stakes in all the wood species. Therefore, the MMC method can be recommended for common use by wood scientists/technologists as the most reliable method for determining the density of softwood species on account of its accuracy.

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