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Utilization Potential of *Eucalyptus camaldulensis* Dehn. as a Construction Material

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ယူကလစ်သစ်၏ဆောက်လုပ်ရေးလုပ်ငန်းသုံးပစ္စည်းအဖြစ်အသုံးပြုနိုင်စွမ်းအလားအလာ

ဝင်းဦးနိုင်၊ လက်ထောက်သုတေသနအရာရှိ
ချိုချိုမြင့်၊ သုတေသနလက်ထောက်–၂
နွယ်နွယ်ဝင်း ၊ သုတေသနလက်ထောက်–၃
သစ်တောသုတေသနဌာန၊ ရေဆင်း
ဒေါက်တာခင်မောင်ဆင့်၊ မန်နေဂျာ
မြန်မာ့သစ်လုပ်ငန်း

စာတမ်းအကျဉ်းချုပ်

ဤသုတေသနတွင် မြန်မာနိုင်ငံ၌ စိုက်ပျိုးသော ယူကလစ်သစ်၏ ဆောက်လုပ်ရေးလုပ်ငန်းသုံး ပစ္စည်းအဖြစ်အသုံးပြုနိုင်စွမ်း အလားအလာကို စမ်းသပ်တင်ပြထားပါသည်။ အဆိုပါလုပ်ငန်းတွင် အသုံးပြုနိုင်မည်ဆိုပါကငင်းသစ်၏အသုံးပြုနိုင်စွမ်းကိုလည်း မြှင့်တင်နိုင်မည်ဖြစ်ပြီး လူထုများသည်လည်း ဈေးသက်သာ၍ ပတ်ဝန်းကျင်နှင့် သဟဇာတဖြစ်သော သစ်နှင့်ဆောက်လုပ်သည့် အိမ်များတွင် နေနိုင်မည်ဖြစ်ပါသည်။ ထိုသို့အသုံးချရေးအတွက် သစ်ရုပ နှင့် အင်အားများသည် အရေးပါသောကြောင့် ၎င်းဂုဏ်သတ္တိများကို စမ်းသပ်ထားပါသည်။ အသက်အရွယ်အလိုက်၊ စိုက်ပျိုးရာဒေသအလိုက်၊ အပင်အချင်းချင်းနှင့်တစ်ပင်အတွင်းဖြစ်ပေါ်တတ်သော ၎င်းဂုဏ်သတ္တိများ၏ ကွဲလွဲချက်များကိုလည်း လေ့လာထားပါသည်။ မကွေး၊ ရေတာရှည်နှင့် သာစည်မြို့နယ်များမှ တစ်နယ်၂ပင်နှုန်းခုတ်ယူခဲ့ပြီး၊ တစ်ပင်စီကိုအောက်ခြေ၊အလယ်နှင့်အထက်ဟု သုံးပိုင်းညီပိုင်းကာရုပဆိုင်ရာ ဂုဏ်သတ္တိများကို ASTM D143-94 (2007) အရလည်းကောင်း၊ အင်အားဆိုင်ရာဂုဏ်သတ္တိများကို BS 373-1973 အရ လည်းကောင်း၊စမ်းသပ်ခဲ့ပါသည်။ ယူကလစ်သည် အလွန်ကျုံ့သော သစ်မျိုးဖြစ်သည်။ သာစည်မြို့နယ်မှ ယူကလစ်သစ်သည် ကျုံ့မှုတွင် အများဆုံးဖြစ်ပြီး သိပ်သည်းမှုတွင်အနည်းဆုံးဖြစ်သည်။ ၎င်းလက္ခဏာ များသည် အသားနုသစ်တွင်ဖြစ်တတ်သော အချင်းအရာများဖြစ်သည်။ ရေတာရှည်မြို့နယ်မှ သစ်သည် အင်အားအကောင်းဆုံးဖြစ်သည်ကိုတွေ့ရပါသည်။ သစ်တစ်ပင် အတွင်းတွင် သစ်အင်အားနှင့် သိပ်သည်းမှုတို့သည် အူမှအကာဆီသို့ တိုးလာသည်ကိုတွေ့ရပြီး အစိုဓာတ်ပါဝင်မှုနှင့်ကျုံ့မှုတို့ လျော့နည်းလာသည်ကိုတွေ့ရသည်။ အပင်အမြင့်တစ်လျောက်တွင် ၎င်းဂုဏ်သတ္တိများ၏ ပြောင်းလဲမှုသည် တိကျသောလမ်းကြောင်းမရှိပေ။ ယူကလစ်၏ သိပ်သည်းမှုနှင့်အင်အားများသည် ကျွန်းနှင့်မြန်မာနိုင်ငံရှိ စီးပွားရေးအရအရေးပါသောသစ်များနှင့်နှိုင်းယှဉ် နိုင်သည်ကိုတွေ့ရသဖြင့် ဆောက်လုပ်ရေးလုပ်ငန်းများတွင် အသုံးပြုနိုင်ပါသည်။ သို့ရာတွင် အသုံးမပြုမီ ၎င်းသစ်ကိုအသုံးပြုမည့် ပတ်ဝန်းကျင်တွင် ဖြစ်ပေါ်မည့် အစိုဓာတ်သို့ရောက်သည်အထိ အခြောက်ခံသင့်ပါသည်။

Utilization Potential of
***Eucalyptus camaldulensis* Dehn. as a Construction Material**

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Abstract

This research tested the suitability of *Eucalyptus camaldulensis* grown in Myanmar as a construction material, to promote its utilization potential and at the same time to give people the opportunity to live in low cost, but environmentally friendly houses. In order to put this species into this application ,physical and mechanical properties were of great importance and thus investigated .Variations in properties of interest were analyzed among different age groups and different localities as well as between and within trees.Two *Eucalyptus camaldulensis* trees were harvested from each of three different localities: Magwe, Yetashe and Tharzi Township.Each sample tree was divided into three equal portions: Base, Middle and Top.Physical and Mechanical Properties were investigated following ASTM D143-94 (2007) and BS 373-1973, respectively.The species has high radial, tangential and volumetric shrinkage values. *Eucalyptus camaldulensis* from Tharzi showed the highest shrinkage, but have the lowest density and specific gravity probably due to high juvenile wood content. Those from Yetashe presented the highest strength whereas those from two other regions produced the same strength. Generally, Density and strength increased from the pith towards the bark whereas moisture content and shrinkage decreased.There was no definitely trend in vertical direction. Density and strength properties are comparable to teak and other commercial timbers of Myanmar and thus high enough to use *Eucalyptus camaldulensis* in medium and light constructions. However, it should be dried to a moisture content it will be in equilibrium with the environment of its use..

Key words: ***Eucalyptus camaldulensis*, Physical and Mechanical Properties, Utilization.**

Contents

1. Introduction

Wood is a natural raw material used in our modern living world nearly everywhere due to its technological properties and aesthetical appearance. There are also many other attributes that make wood a versatile material: its comparative abundance, availability in many species, sizes, shapes, colors and conditions to suit almost every demand, less energy consumption in processing, etc. (Forest Products Laboratory 1999; Risbrudt 2005). Thus, it lends itself to a broad range of applications from light and heavy constructions, vehicles, furniture, decorative, tools and toys to pulp and paper industries.

Moreover, wood forms a biological composite, which has been recognized as the most environmentally friendly engineering material. It is also biodegradable, which has been perceived as a disadvantage of wood in wood protection, but now been accepted as an advantage to dispose off at the end of its service life as it is naturally recycled (Schultz and Nicholas 2008). Therefore, there is a promising trend of increasing employment of wood to various possible applications in the future.

In addition to the vitality and versatility of wood, we can also witness the values of trees before they have been harvested from the forests. Trees enhance aesthetic and environmental character of every region. Forests are renewable and the wood products are sustainable through a wise forest management (Bowyer et al. 2007). When tree grow, they sequester in the production of wood biomass carbon dioxide, a greenhouse gas contributing to global warming (Hill 2006) and thus act as carbon sinks and mitigate global warming as well.

Table 1: Annual world wood harvest in recent years

Year	Roundwood		Fuelwood		Industrial roundwood	
	(mill. m^3)	(%)	(mill. m^3)	(%)	(mill. m^3)	(%)
2004	3411	100	1767	51.8	1644	48.2
2005	3490	100	1799	51.5	1691	48.5
2006	3507	100	1872	53.4	1635	46.6

Sources: FAO 2006; FAO 2007; FAO 2009

Table 2: Production of wood products in Myanmar (1000 m^3 over bark)

Year	1990		2000		2005	
	(1000 m^3)	(%)	(1000 m^3)	(%)	(1000 m^3)	(%)
Industrial roundwood	3397	9	3604	9	3880	9
Fuelwood	35687	91	37104	91	39180	91
Total	39084	100	40708	100	43060	100

Source: FAO 2006

The amount of roundwood produced has increased over the year due to increasing demand induced by population and welfare growth in the world (Table 1) as well as in Myanmar (Table 2). The increase of wood production in Myanmar stems from the increasing domestic timber consumption to develop infrastructure (ITTO 2006).

Boyer et al. (2007) has presented some possible measures to meet growing timber demand: increasing the intensity of management on forest lands, substantially increasing the area of high-yield forest plantation, significantly improving the conversion techniques or shifting increasingly to non-wood raw materials. Among these, plantation forestry has been one of the best measures in the world as well as in Myanmar because of high productivity of uniform product in a short period from a relatively small land planted with very fast growing timber species (Evans 1982). Forest plantation has been embarked on since as early as 1896 with teak in Myanmar, followed by the establishment of other commercial species such as *Xylia dolabriformis, Pterocarpus macrocarpus*, conifers, etc. in the following years (Forest Department 2006).

Taking a look at the Myanmar plantation forestry, eucalypts plantations were begun to establish in 1968 (Forest Department 2006). However, the trial plantations were reported to have been introduced to Myanmar since 1921 (Lwin 1993). Initiated with 12 ha in 1968, it was continually grown till 2003, with annual planting area varying from 30 ha in 1969 to 11,117 ha in 1997. After a hiatus of two years (2004 and 2005), it was regrown in 2006 for over 4,000 ha. The total eucalypt plantation area amounts to 78,700 ha by 2006 (Forest Department 2006) and constitutes 9.4% of the total planted area.

In Myanmar, eucalypts are planted in three types of plantation (village supply, industrial and watershed) to achieve the following objectives (Lwin 1993):

(1) To supply rural community with fuelwood, poles, small timbers and timber for farm implements, and to produce mine props and fishery posts,
(2) To supply raw material for pulp and paper industries,
(3) To enhance erosion protection in the catchment area and to rehabilitate the areas with harsh climatic condition with poor soils, and
(4) To conduct research for other uses and growth studies.

Eucalypts are favored species in plantation forestry worldwide due to their wide adaptability, ease of establishment, higher survival rate, fire resistance, ability to grow on relatively poor soil, higher growth rate, coppicing ability and its economic uses (Malab 1993). Among the so many eucalypt species, *E. camaldulensis* has been reported to outperform other eucalypts regardless of origin (Malab 1993, Lwin 1993; Pruchapruth 1993; Ahmad 1993; Khanal 1993; Santos 1997). Thiep (1993) also reported that *E. camaldulensis* is better adapted to lowlands than other species. In Myanmar, it is the only one planted on a commercial scale starting from 1970, and thus now constitutes nearly 100% of all eucalypt plantations (Lwin 1993; Forest Department 2006).

Eucalypts are among the fastest growing trees with the average MAI of 10-15 m^3/ha/ya from the large scale plantations (Jacobs 1981). However, the growth rate varies with species, site quality, silvicultural practices, species, provenances and genetic improvement. In Burundi, the mean annual increment of eucalypts is as low as to 1-2 m^3/ha/yr whereas it varies from 3-11 m^3/ha/yr in Moroco to 25-30 m^3/ha/yr in Israel and Turkey at a rotation of 7-14 years (Ugalde and Perez 2001). Thus, eucalypt plantations provide higher mean annual increment than teak plantations managed under a rotation of 50-70 yrs, which lies between 1.3 to 3 m^3/ha/yr (Ugalde and Perez 2001).

Nowadays, timber demand in Myanmar is still on the increase, especially for housing constructions. Due to scarcity and high prices of timber, rural people in central dry regions of Myanmar build their houses with available materials like bamboos, palms, etc, which need repairs quite often. Thus, sufficient supply of timber required for housing and other constructions at a reasonable price is essential to enhance their living standard. Considering its large dimensions, wider adaptability, higher performance on poor soils and higher volume increment, and possibility to manage under a short rotation, *E. camadulensis* appears the most promising to meet the need in this aspect. Physical and mechanical properties are of vital importance to its applications where strength is essential. However, no research on this aspect of plantation-grown *E. camaldulensis* of Myanmar has been conducted before. Significant variations in these properties of the same species exist not only between the same regions, but also among different regions. In addition, growth rate, proportion of juvenile wood and subsequently properties of plantation eucalypts overseas are different from those in eucalypt plantation in Australia (Hillis 1984). Thus, this research paper assesses the suitability of *E. camaldulensis* raised in Myanmar as a construction material, and investigates the variations among different ages and different localities as well as between and within trees.

2. Literature review

Eucalypts are initially planted to furnish raw material in pulp and paper industries, in production of particle- and fiberboards, and fuelwood, pole and posts. The production of eucalypts has increased over the year, and research has been oriented to their applications for noble products like furniture and constructions.

Zahid and Ahmad (2002) tested some physical properties and lumber recovery of farm-grown *E. camaldulensis* of three different ages: 5, 8 and 14 years. Radial and tangential shrinkage values are quite close to each other and relatively low, ranging from 5.05% to 6.45% and from 4.75% to 5.53%, respectively. Age has no significant effect on radial shrinkage, but on tangential shrinkage. Density increases with tree age with the youngest having 670 kg/mm^2 and the other age groups having about 700 kg/m^3. However, lumber recovery factor decreases with tree age due to higher potential to become twisted, suggesting it be harvested at a relatively young age of five.

Twelve year old *E. camaldulensis* wood samples have an air-dry density of 600-870 kg/m^3 and shrink radially by 6.8% while air-dry samples of mature trees weigh 913 kg/m^3 and shrink by 8.9% in radial direction (McComb et al. 2004). The five year old hybrids of E. *camaldulensis* x *E. globulus* shrink by 9.6%, 4.9% and 0.4% in tangential, radial and longitudinal directions, respectively (McComb et al. 2004).

Hillis (1984) listed some physical and mechanical properties of mature *E. camaldulensis* of Australian origin as presented in Table 3:

Table 3: Physical and mechanical properties of mature *E. camaldulensis*

Seasoning	Density	MOR	MOE	MCS	Side Hardness	Strength group	Shrinkage
	kg/m^3	N/mm^2	N/mm^2	N/mm^2	N	-	%
Green	645-720	62.2- 64	7750-8600	31.1-34.5	6300-7100	S5	High
12% MC	905-1010	96.7-110	9700-11000	55.3-62.1	10000-11100	SD6	

According to the data as reviewed above, *E. camaldulensis* shrink high, but relatively hard and strong enough to be used in constructions. The wood has also been reported to be durable and fairly resistant to termite attack (Scheffer and Morrell 1998; Brent 2006; Lee et al. 2005), and hence can be used for outdoor and indoor applications without treatment. It is used for earthworks, hydraulic engineering, harbor constructions, bridges, boats, railway ties and pole (Lamprecht 1989; Santos 1997). Thus, this research will hopefully meet the requirements for the acceptance of *E. camaldulensis* grown in Myanmar as a construction material, therefore promote its utilization potential as a solid timber and give the people the opportunity to live in low cost, but environmentally friendly wooden houses.

3. Materials and methods

3.1 Materials

The materials used in this research were planted *E. camaldulensis* trees of different ages, harvested from three different localities: Magway, Yetashe, and Tharzi Tsp. More information on the investigating materials is presented in Table 4.

Table 4: Mean diameter, length of sampled *E. camaldulensis* trees of three localities

Locality	Mean diameter	Length		Mean rainfall
	(cm)	(m)	-	(mm)
Magway	173	5.5		882
Yetashe	132	5.5		1592
Tharzi	130	5.5		763

3.2 Methods

Two trees per locality were tested for shrinkage, density, specific gravity, moisture content, modulus of rupture, modulus of elasticity, axial compression strength, side compression strength and Janka hardness. Physical properties were investigated following ASTM D143-94 (2007) while strength properties were conducted in accordance with BS 373-1973.

Each tree was vertically divided into three equal portions: Bottom (B), Middle (M) and Top (T). Each portion was again horizontally differentiated into three woodzones: Juvenile wood (J), Heartwood (H) and Sapwood (S). Three 100 mm thick disks were cut from the base of each portion for testing physical properties, and the rest portions are used in sample preparation for mechanical properties. Six replications per woodzone were sampled in testing each property, the total number of samples thus being 108 per property.

3.3 Data analysis

Four factors were analyzed as sources of variation: ages or locality with three levels of between-variation (Magway, Yetashe and Tharzi), trees with two levels of between-variation (tree 1 and tree 2), portions or sections with 3 levels of vertical within-variation (bottom, middle and top) and woodzones with three levels of horizontal within-variation (juvenile, heartwood and sapwood). Thus, the statistical design is a completely randomized four-factorial model with six replications. With the help of Statistica software (version 7), the data were subjected to analysis of variance to investigate their influence on physical and mechanical properties. These analysis results are presented in Appendix I (physical properties) and Appendix II (mechanical properties).

4. Results and discussion

4.1 Shrinkage

Table 5 compiles mean values of shrinkage in different wood anatomical directions at three different woodzone levels for three localities. The mean total volumetric shrinkage varies from 11.3% to 17.7% whereas the mean total radial and tangential shrinkage ranges from 5.2% to 6.8% and 6.9% to 9.2%, respectively. The mean values from green to 12% moisture content are generally two third of the total shrinkage. These findings are in line with the results of 39 years old Algerian grown *E. camaldulensis* (Unsal et al. 2003), and comparable to those of five year old hybrid wood of *E. camaldulensis* and *E. globulus* (McComb et al. 2004). Chudnoff (1961) reported about 30% volumetric shrinkage in the core zone and about 10% in the sapwood zone in 18-20 year old trees in Israel.

Table 5: Radial, tangential and volumetric shrinkage of *E. camaldulensis* of different localities (mean values and standard deviations in parenthesis)

Locality	Woodzone	N	R		T		V		Anisotropy
			0%	12%	0%	12%	0%	12%	-
Magway	Juvenile	36	5.8 (0.9)	3.5 (0.5)	7.4 (1.3)	4.4 (0.8)	12.5 (2.2)	12.9 (3.2)	1.28
	Heartwood	36	5.2 (0.7)	3.1 (0.5)	7.0 (1.4)	4.2 (0.8)	11.1 (1.5)	9.7 (1.7)	1.35
	Sapwood	36	4.6 (0.6)	2.7 (0.3)	6.3 (1.1)	3.8 (0.6)	10.3 (1.6)	9.3 (2.1)	1.37
	Mean	**108**	**5.2 (0.7)**	**3.1 (0.4)**	**6.9 (1.3)**	**4.1 (0.7)**	**11.3 (1.7)**	**10.6 (2.3)**	**1.33**
Yetashe	Juvenile	36	7.7 (1.0)	4.6 (0.6)	10.5 (1.4)	6.3 (0.9)	19.9 (4.0)	7.5 (1.3)	1.36
	Heartwood	36	6.1 (0.7)	3.7 (0.4)	9.0 (1.3)	5.4 (0.8)	15.2 (1.2)	6.6 (0.9)	1.48
	Sapwood	36	5.6 (0.6)	3.4 (0.4)	8.1 (0.4)	4.9 (0.3)	12.5 (1.2)	6.2 (1.0)	1.45
	Mean	**108**	**6.5 (0.7)**	**3.9 (0.5)**	**9.2 (1.0)**	**5.5 (0.7)**	**15.9 (2.1)**	**6.8 (1.0)**	**1.42**
Tharzi	Juvenile	36	8.3 (1.3)	5.0 (0.8)	10.9 (1.0)	6.5 (0.6)	21.5 (5.3)	11.9 (2.4)	1.31
	Heartwood	36	6.6 (0.7)	3.9 (0.4)	8.5 (1.3)	5.1 (0.8)	16.2 (2.8)	9.1 (0.7)	1.29
	Sapwood	36	5.7 (0.6)	3.4 (0.3)	7.1 (1.4)	4.2 (0.8)	15.5 (3.5)	7.5 (0.7)	1.25
	Mean	**108**	**6.8 (0.8)**	**4.1 (0.5)**	**8.8 (1.2**	**5.3 (0.7)**	**17.7 (4.0)**	**9.5 (1.3)**	**1.29**
Global mean		**324**	**6.2 (0.7)**	**3.7 (0.5)**	**8.3 (1.2)**	**5.0 (0.7)**	**14.9 (2.6)**	**9.0 (1.5)**	**1.35**

R, T, V = radial, tangential and volumetric shrinkage; 0% = shrinkage from green to oven-dry state
12% = shrinkage from green to 12% moisture content; N (number of specimens per woodzone) = 36

As presented in Table 5 and Figure 1 (volumetric shrinkage), shrinkage decreases from pith outwards at a given height, with juvenile wood shrinking significantly higher than other woodzones. Hillis (1984) reviewed shrinkage behavior of *E. camaldulensis* and found sapwood shrinks 74% of the adjacent heartwood and the outer heartwood shrinks 87% of the inner heartwood. Chudnoff (1961) also reported a decrease from pith to outer heartwood zone and then increase towards sapwood again. These findings are in agreement with the decreasing pattern of shrinkage from the pith outwards found in this research. Juvenile wood has cell structures different from normal wood such as cell length, cell wall thickness, cell vertical orientation, and microfibril angles of the S2 layer (Dinwoodie 2000). It is characterized by spiral grain, compression wood, greater microfibril angle and shorter cells (Bowyer et al. 2007; Tsoumis 1991; Panshin and de Zeeuw 1980), which results in higher shrinkage. In vertical direction, no clear trend of increase or decrease is observed with height. Although juvenile wood has the lowest volumetric shrinkage in the middle section, no significant differences exist within trees of the same locality.

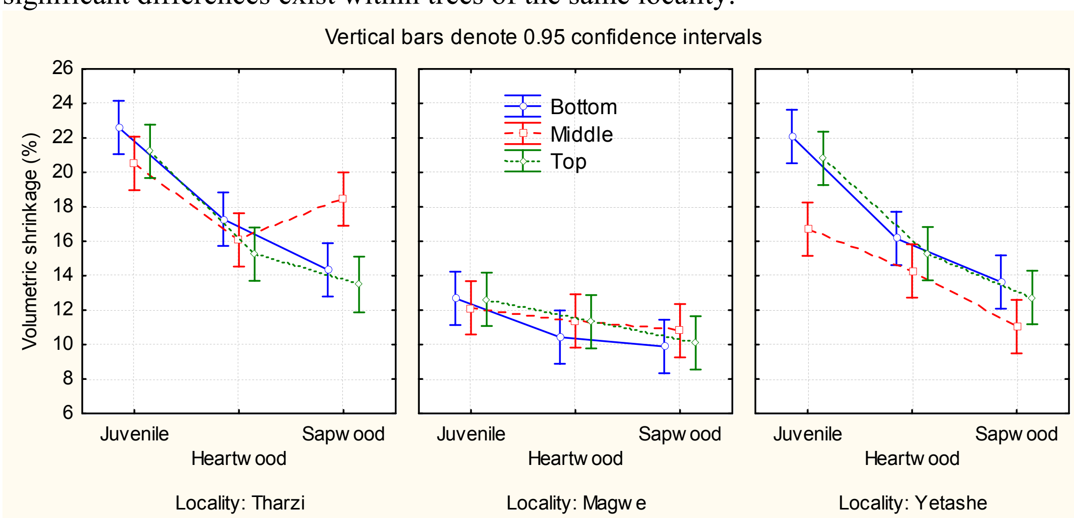

Figure 1: Total volumetric shrinkage from pith outwards at three different heights

With respect to locality, *E. camaldulensis* of Magway origin shrinks significantly less than those of the two other localities. These significant differences can be attributed to variations in wood structure arising from differences in genetic constitution, growing environment, latitude and altitudes on one hand (Tsoumis 1991), and to the effect of ages on it (Zahid and Ahmad 2002).

Despite low anisotropy of about 1.35 (ratio of tangential to radial shrinkage), *E. camaldulensis* shows high absolute shrinkage values. Only timbers having a low T/R ratio and low absolute dimensional changes are assumed to be best suited to uses involving critical dimensional stability (Panshin and de Zeeuw 1980). Relatively high amount of juvenile wood and brittle heart and very high density (Table 6) accounts for the high shrinkage of this species. Thus, for the application of timbers with relatively high shrinkage like *E. camaldulensis*, they should be seasoned to the expected equilibrium conditions which they will establish with the surrounding air (Dinwoodie 2000).

4.2 Density, specific gravity and moisture content

Results on density and specific gravity of *E. camaldulensis* are presented in Table 5. Depending on the moisture levels of the specimens, density ranges from 1242 to 1321 kg/m^3 (green), from 1056 to 1171 kg/m^3 (12% MC) and from 994 to 1037 kg/m^3 (oven-dry).

Similarly, basic specific gravity also varies from 0.82 to 0.90 whereas air-dry specific gravity ranges from 0.94 to 1.05. The density and specific gravity values in this research were exceptionally higher than those of five, eight and 14 year old *E. camaldulensis* trees grown in Pakistan (Zahid and Ahmad 2002), those of trees of unknown age grown in Turkey (Unsal et al. 2003), those of four, six and eight year old trees of Thailand (Pitsuttipiched 2004), but similar to those grown in Australia and South Africa (Chudnoff 1961). These higher differences in density and specific gravity are attributable to the age (Zahid and Ahmad 2002; Pitsuttipiched 2004) and locality (Gerhards, 1965). Hillis (1984) also pointed out considerable variations in density between and within eucalypt species and trees due to variation in fiber properties and proportion of different cell types.

Table 5: Density, specific gravity and moisture content of *E. camaldulensis* (mean values and standard deviations in parenthesis)

Locality	Woodzone	N	Density (kg/m^3)			Specific gravity		MC%
			Green[1]	12%MC[2]	Oven-dry[3]	Basic[4]	12% MC[5]	
Magway	Juvenile	36	1298 (31)	1108 (61)	976 (43)	0.85 (0.04)	0.99 (0.05)	52.2 (5.7)
	Heartwood	36	1336 (16)	1206 (44)	1033 (32)	0.92 (0.03)	1.08 (0.04)	45.4 (3.9)
	Sapwood	36	1328 (25)	1200 (30)	1020 (20)	0.92 (0.02)	1.07 (0.03)	45.2 (2.8)
	Mean	**108**	**1321 (24)**	**1171 (45)**	**1010 (32)**	**0.90 (0.03)**	**1.05 (0.04)**	**47.6 (4.2)**
Yetashe	Juvenile	36	1268 (73)	1027 (83)	991 (116)	0.80 (0.13)	0.92 (0.16)	61.8 (18.6)
	Heartwood	36	1320 (34)	1171 (114)	1056 (84)	0.90 (0.08)	1.05 (0.10)	48.2 (9.7)
	Sapwood	36	1331 (25)	1225 (80)	1064 (56)	0.93 (0.05)	1.09 (0.07)	43.2 (6.1)
	Mean	**108**	**1306 (44)**	**1141 (126)**	**1037 (85)**	**0.87 (0.08)**	**1.02 (0.11)**	**51.1 (11.5)**
Tharzi	Juvenile	36	1193 (73)	958 (101)	951 (51)	0.75 (0.07)	0.85 (0.09)	60.2 (7.8)
	Heartwood	36	1270 (25)	1094 (50)	1009 (29)	0.85 (0.03)	0.98 (0.04)	50.4 (5.4)
	Sapwood	36	1263 (58)	1122 (64)	1023 (37)	0.86 (0.04)	1.00 (0.06)	46.3 (4.0)
	Mean	**108**	**1242 (52)**	**1056 (72)**	**994 (39)**	**0.82 (0.05)**	**0.94 (0.06)**	**52.3 (5.7)**
Global mean		**324**	**1290 (40)**	**1123 (81)**	**1014 (52)**	**0.86 (0.05)**	**1.00 (0.07)**	**50.3 (7.1)**

[1]calculated on the basis of saturated green weight and maximum swollen volume; [2]estimated by the formula $\rho=1000\ G_{12}\ (1+12/100)$; [3]calculated on the basis of oven-dry volume and weight; [4]calculated on the basis of saturated maximum swollen volume and oven-dry weight; [5]estimated from the relation $G_{12} = G_b\ (1-0.265*0.6*G_b)$, where G_{12} is specific gravity at 12% MC and G_b is basic specific gravity

In horizontal direction, juvenile wood has the lowest density/specific gravity (Figure 2), which is a reflection of the presence of a high proportion of thin-walled cells and relatively few latewood cells, and low cellulose and high lignin content in the juvenile wood (Bowyer et al. 2007). Similar increasing patterns of density/specific gravity with increasing distance from the pith have been observed for *E. camaldulensis* and other eucalypts (Hillis 1984). Chudnoff (1961) also reported the increase of specific gravity in the heartwood region from pith outwards, and then the decrease in the sapwood region.

In vertical direction, there is no definite tendency of increasing or decreasing with height, but the top portion seems to have the lowest density and the highest moisture content as depicted in Figures 2 and 3, respectively. Hillis (1984) observed similar variation patterns of density with height for different eucalypts including *E. camaldulensis*. Chudnoff (1961), however, reported the significant increase of density with height in sapwood region, but no significant differences in heartwood zones.

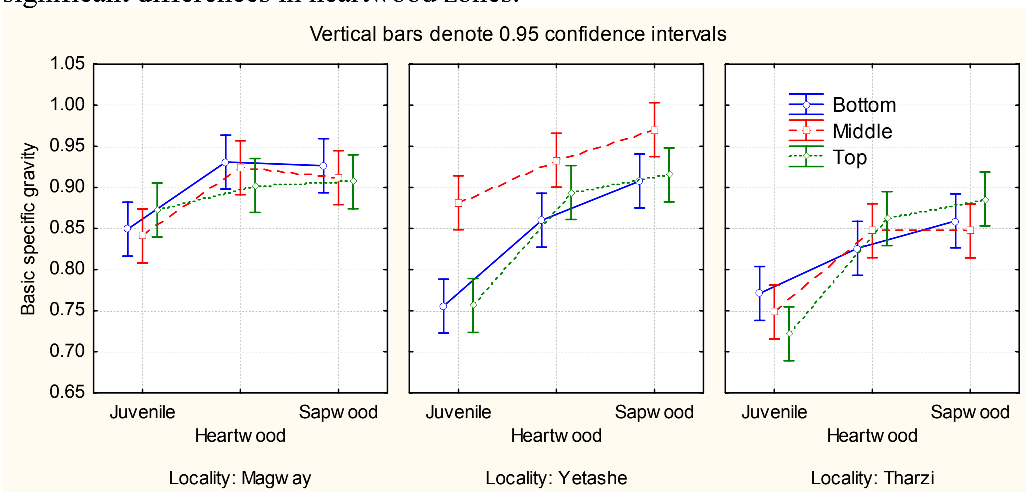

Figure 2: Basic specific gravity (oven-dry weight and green volume) of *E. camaldulensis* varying from pith outwards at three different heights

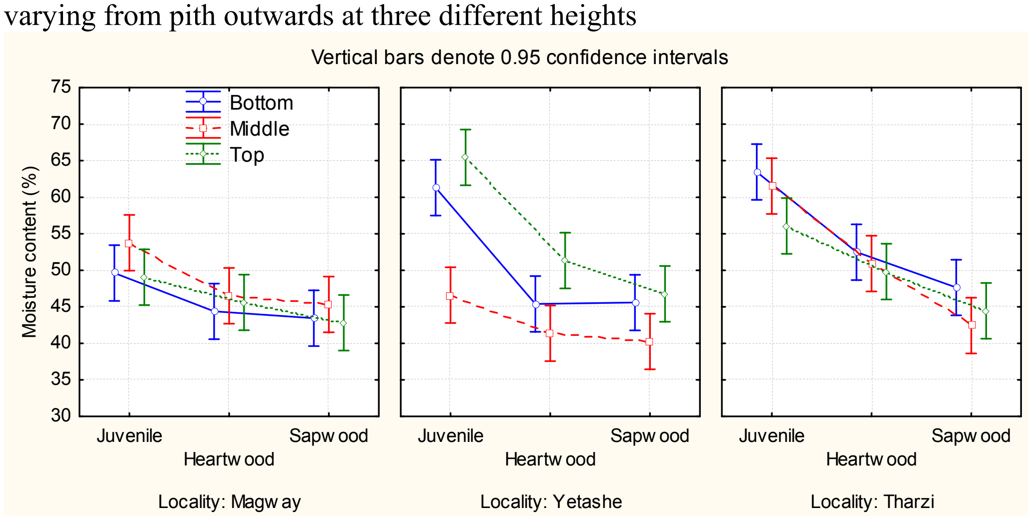

Figure 3: Moisture content of E. camaldulensis varying from pith outwards at three different heights

The mean moisture content of *E. camaldulensis* varies from 47.6% to 52.3%, decreasing with increasing tree age as presented in Table 5. These values are comparable to the moisture content of *E. camaldulensis* grown in Pakistan, which range from 43.7% to 45.8% and decrease with increasing tree age (Zahid and Ahmad 2002). In horizontal direction, the moisture content decreases to the bark. However, it is not increasing or decreasing in vertical direction. Chudnoff (1961) also reported the decreasing pattern from pith to the heartwood zone and the increasing pattern in the sapwood region with height.

4.3 Strength properties

The average results of each woodzone for three localities are presented in Table 6, together with standard deviations in parenthesis. As the moisture content of dry tests pecimens is not exactly 12%, but varied by about ±2%, adjustments are made by calculating changes in properties due to 1% MC change from the green and air-dry test data, with the assumption that fiber saturation point is 30% and the properties change in a linear relation with moisture content below it.

Table 6: Mechanical properties of *E. camaldulensis* (mean values and standard deviations in parenthesis)

Locality	Woodzone	Seasoning	MC (%)	Static bending			Compression parallel to grain		Compression perpendicular to grain	Hardness	
				FS@PL (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)	FS@PL (N/mm^2)	MCS (N/mm^2)	FS@PL (N/mm^2)	Side (kN)	End (kN)
Magway	J	Green	52.2 (5.7)	62.3 (9.0)	86.1 (13.8)	9177 (1530)	30.9 (6.2)	37.0 (6.0)	19.2 (4.1)	2.1 (0.7)	3.2 (0.7)
		Air-dried	12.0	72.4 (11.8)	105.3 (16.3)	13015 (2817)	37.7 (8.9)	51.2 (7.3)	21.6 (4.5)	3.3 (1.0)	4.2 (1.1)
	H	Green	45.4 (3.9)	62.7 (7.2)	88.2 (13.1)	9090 (1357)	29.2 (5.7)	37.5 (6.4)	26.9 (3.2)	3.0 (0.6)	3.7 (0.4)
		Air-dried	12.0	67.9 (11.3)	100.6 (20.0)	11689 (2791)	35.6 (7.1)	52.5 (6.1)	26.4 (4.4)	4.3 (1.1)	4.5 (1.3)
	S	Green	45.2 (2.8)	60.0 (6.8)	84.2 (12.4)	8223 (1602)	31.5 (7.4)	38.7 (7.4)	25.9 (4.5)	3.1 (0.6)	4.0 (0.4)
		Air-dried	12.0	66.0 (15.3)	96.0 (20.0)	11274 (2350)	35.3 (7.3)	51.6 (8.3)	25.0 (2.3)	4.1 (0.9)	4.7 (1.2)
Yetashe	J	Green	61.8 (18.6)	56.4 (13.1)	78.9 (26.4)	11675 (4961)	29.4 (9.6)	35.0 (10.3)	15.7 (6.1)	2.6 (1.0)	2.7 (0.8)
		Air-dried	12.0	81.2 (21.1)	109.4 (31.8)	15863 (4070)	42.8 (13.5)	52.8 (13.8)	19.8 (5.7)	3.4 (1.2)	4.4 (1.4)
	H	Green	48.2 (9.7)	63.6 (15.0)	98.3 (24.4)	12143 (4038)	38.2 (8.4)	44.9 (8.4)	21.3 (4.9)	3.6 (0.8)	3.6 (0.7)
		Air-dried	12.0	80.4 (20.3)	121.0 (28.5)	14850 (3944)	44.5 (11.6)	57.2 (10.3)	24.1 (4.0)	4.5 (1.3)	5.0 (1.5)
	S	Green	43.2 (6.1)	68.2 (11.5)	108.0 (15.2)	12757 (2211)	37.9 (8.2)	44.8 (7.9)	23.1 (5.9)	4.1 (0.9)	4.0 (0.7)
		Air-dried	12.0	73.6 (18.7)	114.2 (31.6)	14173 (2898)	37.8 (10.3)	54.4 (9.2)	25.5 (4.9)	4.9 (1.4)	5.3 (1.7)
Tharzi	J	Green	60.2 (7.8)	57.6 (12.5)	70.2 (20.9)	10085 (2925)	26.7 (4.9)	31.6 (5.9)	15.8 (5.1)	1.5 (0.5)	2.5 (0.5)
		Air-dried	12.0	64.7 (11.5)	84.5 (26.9)	10745 (2449)	46.4 (10.2)	58.2 (7.8)	22.2 (6.1)	3.2 (0.8)	4.6 (1.2)
	H	Green	50.4 (5.4)	67.3 (14.0)	95.3 (26.9)	11347 (2840)	33.9 (6.4)	39.8 (6.8)	22.9 (4.8)	2.3 (0.6)	3.3 (0.5)
		Air-dried	12.0	73.7 (14.8)	107.0 (33.3)	10514 (3457)	43.1 (15.9)	57.8 (11.0)	23.5 (4.6)	3.9 (0.8)	4.7 (1.3)
	S	Green	46.3 (4.0)	64.6 (17.3)	94.2 (28.3)	10244 (3210)	32.2 (7.1)	38.9 (7.4)	24.1 (4.2)	2.7 (0.5	3.7 (0.6)
		Air-dried	12.0	80.2 (16.7)	124.1 (34.5)	11345 (2900)	46.0 (16.7)	58.5 (13.8)	26.4 (3.7)	4.4 (0.9)	5.0 (1.6)
Global mean		Green	50.3 (7.1)	62.5 (11.8)	89.2 (20.2)	10527 (2742)	32.2 (7.1)	38.7 (7.4)	21.6 (4.7)	2.8 (1.0)	3.4 (0.8)
		Air-dried	12.0	73.3 (15.7)	106.9 (27.0)	12607 (3075)	41.0 (11.3)	54.9 (9.7)	23.8 (4.5)	4.0 (1.2)	4.7 (1.4)

J= juvenile wood; H= heartwood; S= sapwood;MC=moisture content; FS@PL = fiber stress at proportional limit; MOR= modulus of rupture; MCS= maximum crushing strength; Side= lateral; End= axial; N=36/woodzone

E. camaldulensis is a very hard timber with an average modulus of rupture of 89 N/mm^2 and modulus of elasticity of 10527 N/mm^2 at water-saturated state and of 107 N/mm^2 and 12607 N/mm^2 at 12% moisture content. These two properties prove the suitability of *E. camaldulensis* as beams in constructions. Moreover, it also has other high properties like maximum crushing strength and hardness and thus can be used as posts and props, and flooring materials.

As presented in Table 7, the strength properties of *E. camaldulensis* are similar to those of teak, a royal timber of Myanmar, but somewhat lower than those of very strong timbers *Xylia dolabriformis* and *Dipterocarpus tuberculatus*. However, it has higher specific gravity than those species listed in Table 7. These results support the findings by Chudnoff (1961), who found that 18-20 year old *E. camaldulensis* grown in Israel has lower strength than timbers of the same density. Thus, Hillis (1984) made a remarkable conclusion that wood density has an appreciable effect on the mechanical and other properties, but is not a direct indication of stiffness, strength, toughness, etc. of a timber. This phenomenon is attributable to the brittle heart usually found in *E. camaldulensis* (Chudnoff 1961).

Table 7: Comparison of properties of *E. camaldulensis* with those of commercial timbers

Species	Seasoning	Specific gravity	Total radial shrinkage (%)	Total tangential shrinkage (%)	Modulus of rupture (N/mm^2)	Modulus of elasticity (N/mm^2)	Maximum crushing strength (N/mm^2)	Side hardness (Janka) (kN)
Teak[1]	Green	0.55	2.5	5.8	80.0	9400	41.1	4.1
	12%	-	-	-	100.7	10700	58.0	4.4
Pyinkado[2]	Green	0.78	3.3	6.7	107.6	15582	55.3	-
	12%	0.81	-	-	137.9	17237	76.5	-
In[1,3]	Green	0.69	5.6	10.7	82.0	11800	39.2	4.7
	12%	0.77	-	-	133.0	15378	50.0	5.6
E.camaldulensis	Green	0.86	6.2	8.3	89.2	10527	38.7	4.4
	12%	1.00	3.7	5.0	106.9	12607	54.9	4.0

[1]Forest Products Laboratory 1999; [2]Gerry and Drow 1953; [3]Sint and Hapla 2008
Teak = *Tectona grandis*; Pyinkado = *Xylia dolabriformis*, Padauk = *Pterocarpus macrocarpus*; In = *Dipterocarpus tuberculatus*

In comparison with the strength properties of *E. camaldulensis* grown in Myanmar and other regions given in Chudnoff (1961), modulus of rupture, modulus of elasticity and maximum crushing strength are comparable from one region to another. *E. camaldulensis* of Myanmar origin has somewhat lower strength than those of the same density like South African, probably due to higher brittle heart content.

Data analysis results show that significant differences exist in almost all properties between localities, at both green and dry conditions. As depicted in Figure 3, Yetashe grown *E. camaldulensis* has the highest strength properties and differs significantly from the other two localities.

In horizontal direction, the strength property is increasing outwards from the pith (Figure 4). The increasing trend holds true for basal portion, but the trend is decreasing in the top portion due to the decrease of juvenile wood in this zone. In vertical direction, the trend is not clear in any wood zone. Chudnoff (1961) reported an increase of strength properties from pith outwards.

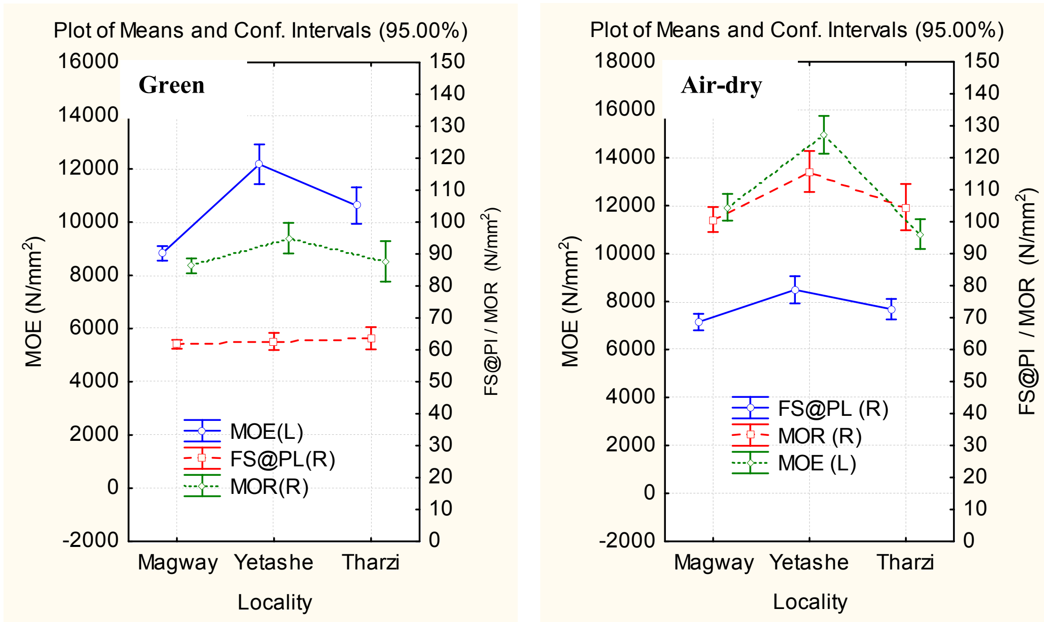

Figure 3: Green and air-dry static bending strength of *E. camaldulensis* grown in three localities

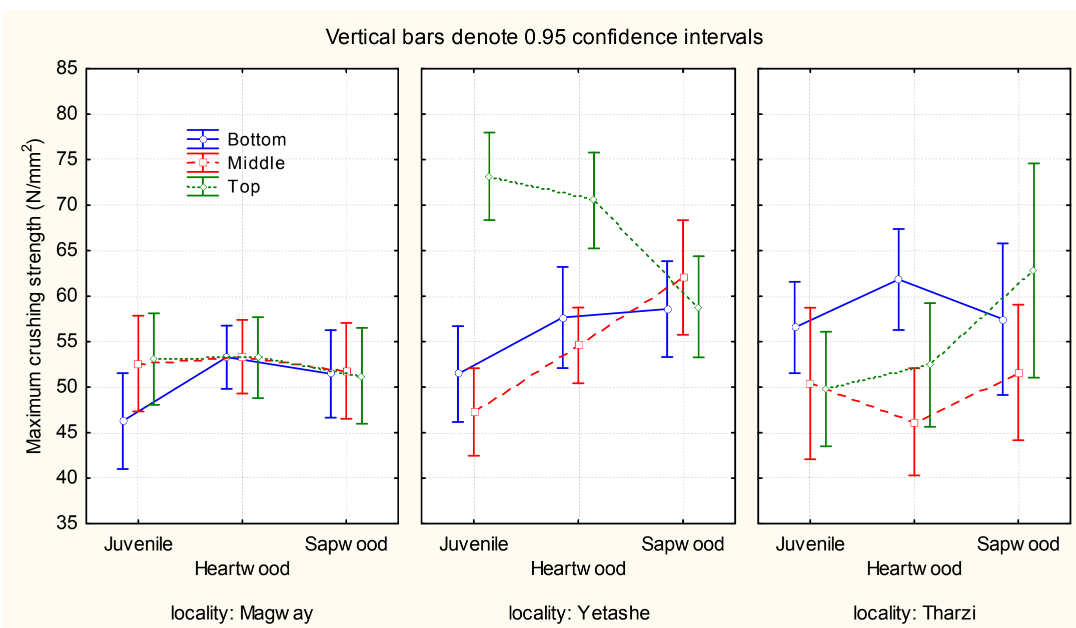

Figure 4: Horizontal variation of maximum crushing strength of *E. camaldulensis* grown at three heights

5. Conclusion

The results of this study can be summarized as follows:

- The species has high shrinkage values in radial and tangential direction, and thus high volumetric shrinkage values. This high shrinking reflects its high density and is also attributable to high percentage of juvenile wood and brittle heart.

- Density/specific gravity results of this research are comparable to those of Australian and African grown *E. camaldulensis*, but relatively higher than those of other regions.

- Despite its relatively high density, this species has remarkable lower strength than other hardwoods of the same density/specific gravity. Thus, these variables should not be used as direct indications to toughness, strength, and stiffness of this wood.
- Variations in shrinkage and density/specific gravity are more pronounced and decreasing from pith outwards. Juvenile wood is characterized by higher moisture content and shrinkage, but lower density and strength. Care should be given enough to the uses of this wood in furniture industries due to the possibility of warping, crooking, bowing, loosening, gaping, etc. In vertical direction, there is no definite trend in the variations of properties due to decreasing juvenile content with height.
- With respect to growth sites, *E. camadulensis* trees harvested from Tharzi show the highest shrinkage, but have the lowest density/specific gravity probably due to high juvenile wood content. Those from Yetashe present the highest strength properties, the two other regions producing the same strength properties.
- Density, specific gravity and strength properties are comparable to teak and other commercial timbers of Myanmar and thus high enough for *E. camaldulensis* to be used in constructions and housing.
- Due to its high shrinkage, careful drying is recommended to reach a moisture content of the environment in which it is used.

Appendix I: Analysis of variance for physical properties

Sources of variation	P-values					
	R	T	V	B. sp.gr	Od. den	MC%
Intercept	**	**	**	**	**	**
{1}Locality	**	**	**	**	**	**
{2}Tree	ns	**	**	**	**	**
{3}Section	**	**	**	**	**	**
{4}Woodzone	**	**	**	**	**	**
Locality*Tree	**	**	**	**	**	**
Locality*Section	**	**	**	**	**	**
Tree*Section	**	**	**	**	**	**
Locality*Woodzone	**	**	**	**	**	**
Tree*Woodzone	**	**	**	ns	**	**
Section*Woodzone	ns	**	**	**	**	**
Locality*Tree*Section	**	**	**	**	**	**
Locality*Tree*Woodzone	**	**	**	**	**	**
Locality*Section*Woodzone	**	**	**	**	**	**
Tree*Section*Woodzone	**	**	**	**	**	ns
1*2*3*4	**	**	**	**	**	**

[*] significantly different at 5% probability level; [**] significantly different at 1% probability level; [ns]not significant
R= total radial shrinkage; T= total tangential shrinkage; V= total volumetric shrinkage; B. sp.gr= basic specific gravity; Od. den= oven-dry density; MC= green moisture content

Appendix II: Analysis of variance for mechanical properties

Sources of variation	P-values							
	Green				Air-dry			
	FS@PL	MOR	MOE	MCS	FS@PL	MOR	MOE	MCS
Intercept	**	**	**	**	**	**	**	**
{1}Locality	ns	**	**	**	**	**	**	**
{2}Tree	**	**	**	**	**	**	**	**
{3}Section	**	**	**	**	**	ns	**	**
{4}Woodzone	**	**	**	**	ns	**	**	*
Locality*Tree	**	**	**	**	**	**	**	**
Locality*Section	**	**	**	**	**	**	**	**
Tree*Section	ns	ns	**	**	**	**	**	ns
Locality*Woodzone	**	**	**	**	**	**	**	ns
Tree*Woodzone	ns	ns	*	ns	ns	ns	ns	ns
Section*Woodzone	ns	ns	*	ns	*	ns	ns	ns
Locality*Tree*Section	**	**	**	**	**	**	**	**
Locality*Tree*Woodzone	**	**	**	**	**	**	**	**
Locality*Section*Woodzone	ns	ns	*	ns	ns	*	ns	ns
Tree*Section*Woodzone	**	**	**	*	ns	ns	ns	ns
1*2*3*4	*	ns	ns	ns	ns	ns	ns	ns

[*] significantly different at 5% probability level; [**] significantly different at 1% probability level; [ns]not significant
FS@PL= fiber stress at proportional limit in static bending test; MOR= modulus of rupture; MOE= modulus of elasticity in static bending test; MCS= maximum crushing strength

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