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Original article

Natural durability, physical and mechanical properties of Atlas cedar (*Cedrus atlantica* Manetti) wood from Southern Italy

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Abstract – This paper deals with the technological characterisation of Atlas cedar wood from artificial plantation in South Italy. Atlas cedar seems to be one of the most promising species for reforestation in Central-South Italy, due to its ecological adaptability, quality of standing trees, even without thinnings and pruning, and productivity of the stands. From a 30-year-old stand in Sicily 6 trees were selected in order to analyse the natural durability of wood against fungi, according to European Standards, and the main physical and mechanical properties from clear specimens, according to ISO Standards. The heartwood resulted classified from "durable" to "very durable", while sapwood is "not durable". The wood is quite dense, taking into account the fast-grown characteristics of the stand, but the volumetric shrinkage is limited and the ratio between tangential and radial shrinkages is less than 1.5. Mechanical characteristics show a wood with a quite high ratio of static quality. From first results the Atlas cedar seems to be a promising tree species from ecological and silvicultural point of view.

wood / durability / properties / Atlas cedar / South Italy

Résumé – Durabilité naturelle et propriétés physiques et mécaniques du bois de cèdre de l'Atlas (*Cedrus atlantica* Manetti), de l'Italie du sud. Les auteurs ont étudié la caractérisation technologique du bois de cèdre de l'Atlas qui provient de plantations artificielles de l'Italie du sud. Le cèdre de l'Atlas semble être une des espèces qui pourra obtenir de bons résultats dans la reforestation en Italie du centre et du sud, soit pour sa faculté d'adaptation écologique, soit pour la qualité des arbres sur pied, même sans opérations d'éclaircie et d'élagage, et enfin pour la productivité des plantations. Dans une région de Sicile on a prélevé d'une plantation de 30 ans 6 arbres pour analyser leur durabilité naturelle vis-à-vis des champignons lignivores, selon les normes européennes, et les caractéristiques physiques et mécaniques d'échantillons, selon les normes ISO. On peut classifier le duramen de « durable » à « très durable », l'aubier au contraire est « non durable ». Le bois est assez dense si l'on considère les caractéristiques de croissance rapide de la plantation, mais le retrait volumétrique est limité et le rapport entre le retrait tangentiel et le retrait radial est inférieur a 1,5. Les caractéristiques mécaniques montrent un bois avec une assez haute cote spécifique de qualité. Selon ces premiers résultats le cèdre de l'Atlas semble être, du point de vue écologique et sylvicultural, très satisfaisant.

bois / durabilité / propriétés / cèdre de l'Atlas / Italie du sud

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ABBREVIATIONS

List of symbols used in the text, in alphabetical order.

Symbol	Units	Description
DBH	cm	Diameter at breast height
f.s.p.	%	fiber saturation point
H	m	Height
m.c.	%	Moisture content
MOE	MPa	Modulus of elasticity
MOR	MPa	Modulus of rupture
R.H.	%	Relative humidity

1. INTRODUCTION AND AIM OF THE PAPER

The Atlas cedar wood has a fine texture, a fragrant smell and it is easy to be converted.

The aim of the paper is an improvement of the technological characteristics and a valorisation of the wood from Atlas cedar, a forest species largely introduced in southern Italy in reforestations.

Even if they rarely had any thinning or pruning, those artificial plantations showed good increments in many European regions where Atlas cedar has been introduced (France, Italy, Hungary, Bulgaria). That's why many countries started finalised projects toward the improvement of the silvicultural management of existent stands and of the knowledge of that wood, in order to find its best end use.

2. DISTRIBUTION AND ECOLOGICAL CHARACTERS

The *Cedrus* genus includes three species native from Mediterranean mountains and one species from Himalaya:

– *Cedrus atlantica* Manetti, from Algeria and Morocco;

– *Cedrus libani* Rich., from Asia Minor;

– *Cedrus brevifolia* (Hooker fil.) Henry, from Cyprus;

– *Cedrus deodara* Don, from Afghanistan and southern slopes of western Himalaya.

These species are interfertile, mostly *Cedrus libani* and *Cedrus atlantica*, with a lot of ornamental cultivars, frequently giving origin to hybrids.

The Atlas cedar can reach 50 m height and 1.50 m DBH. The species is light demanding and cannot stand too much cold and long winters, withstanding summer droughts only when the year precipitation exceeds the 800 mm.

Cedar needs silicaceous soils, while the carbonatic ones are tolerated when deep and in sufficiently rainy stations. The specie's optimum is located in elevations from 1 400 m to 2 000 m a.s.l., with rainfalls from 900 to 1 500 mm per year.

The young tree has a slender and elegant bearing, as adult shows an expanded crown, without showing the tabular crown typical of the Lebanon cedar, from which it is also differentiated by shorter needles.

Bark is light greyish, smooth and brilliant till about 25 years, and then it cracks in small scales.

The needles are 15–20 mm long, the cones are green, upright, 8 cm long and with a diameter of about 7.5 cm, then smaller than the Lebanon cedar ones. Mature cones are brown.

Seeds are oval and flat, 10–12 mm long, with a 2 cm long wing. The plantula has from 7 to 10 cotyledons.

The indigenous range of the Atlas cedar is this way distributed [3]:

– In Morocco: in the Rif Region (about 16 000 ha), in Medium Atlas (about 100 000 ha) and Grand Eastern Atlas (about 10 000 ha);

– In Algeria the range of cedar is fragmented, in different ecological regions, with a total extension of about 20 000 ha.

In the native range, this species has a good adaptability and lives in high atmospheric humidity regions in Morocco as well as in xerophile environments in other Moroccan and Algerian regions [3].

In Europe the Atlas cedar was introduced during the first half of 19th century as an ornamental tree and only in a second time for forest purposes. In many European countries and in USA some introduction trials are now under way, in order to evaluate the real diffusion possibility.

The first forest diffusion trials in Italy started during the second half of 19th century in Tuscany.

Starting during the 30's of 20th century some shields plantations were made, mixing cedar with other species, particularly with black pine (*Pinus nigra* Arnold).

According to some estimations, at present the surface covered by the Atlas cedar in Italy is about 1 000 ha [3]. The highest diffusion is in Tuscany, with recent extensive plantations in Abruzzo, Molise, Calabria, Sardinia and Sicily.

Often it was introduced in chestnut coppices and in oak stands, mixed with Turkey Oak (*Quercus cerris* L.), pubescent Oak (*Quercus pubescens* Wild.) and evergreen Oak (*Quercus ilex* L.), or in Hop Hornbeam (*Ostrya* sp.) stands, where it forms sparse formations.

The data about the growth in native ranges vary according to the soil and climate conditions and to other factors such as composition, structure, age and cutting system. Increments vary indeed between 1–1.5 and 6–7 m^3 ha^{-1} per year in the best conditions.

The increments variation recorded in Italy is mostly caused by the soil: average increments are between 3 and 14 m^3 ha^{-1} per year.

3. MATERIALS AND METHODS

3.1. Materials

The trees utilised for the trials come from thirty years old reforestation plants in Sicily, from mountains located between the Provinces of Palermo and Agrigento.

The forest has a changing exposition from SW to NW and an elevation from 1 090 to 1 250 m a.s.l. Mean precipitations are 800 mm per year.

The soils are clay with sub alkaline reaction, brown, leached, typical of the inner, hilly regions of Sicily.

The stand is mixed, with a percent variation of European Black Pine (*Pinus nigra* Arnold) and Aleppo Pine (*Pinus halepensis* Mill.) at lower elevations.

Six trees were randomly selected with following medium characteristics: age = 31 years, H = 12.7 m, DBH = 23.6 cm. The diametric percentage of heartwood at 1.30 m was 36.2%.

From the roundwood the DBH bolts were obtained, from which the radial boards were sawn. For the different purposes the sample were obtained from those boards, according to the scheme on *table I*.

Table I. Performed tests, dimensions of utilised samples and standard followed for the tests.

Test type	Sample dimension (cm) long × transerve dimensions	Standard reference
Natural durability	5 × 2.5 × 1.5	UNI EN 113; EN 350/1
Density	2.5 × 2 × 2	ISO 3131
Shrinkages	2.5 × 2 × 2	ISO 4858, ISO 4469
Bending MOR	32 × 2 × 2	ISO 3133
Bending MOE	32 × 2 × 2	Dynamic method
Compression	3 × 2 × 2	ISO 3787
Shear	2 × 2 × 2	ISO 3347

3.2. Methods for natural durability tests

The analysis of the natural durability to wood-destroying fungi (Basidiomycetes) of Atlas cedar wood was performed according to the European standards EN 350-1 and EN 113.

Samples were selected in order to analyse different zones of the section:

- zone A, sapwood near cambial region;
- zone B, sapwood near heartwood;
- zone C, external heartwood;
- zone D, inner heartwood (three cm from the pith).

Before the test, all the samples were put into a climatic chamber in order to reach the equilibrium m.c. 12%.

The standard previews the calculation of the theoretical oven-dry mass (*Mto*), obtained from the measurement of the m.c. on another series of oven dried samples, of each test specimen before tests as follows:

$$Mto = \frac{Mu}{(100+u)}$$

where *Mu* is the mass of the samples to be tested after conditioning.

Each sample was placed side by side with a control sample of sapwood of Scots Pine (*Pinus sylvestris* L.), as a reference species, selected by the standard for the durability tests on softwoods.

The wood was tested for the durability against the following fungi:

– *Coniophora puteana* (Schumacher e Fries) Karsten, strain BAM Ebw. 15;

– *Poria placenta* (Fries) Cooke sensu J. Eriksson strain FPRL 280;

– *Gloeophyllum trabeum* (Persoon ex Fries) Murril, strain BAM Ebw. 109.

The calculation of the natural durability was made through the measurement of the mass loss of wood due to a fungal attack under controlled environment (22 ± 1 °C; 70 ± 5% R.H.) after four months.

According to the mass loss due to the fungal attack, referred to the oven dry weight, the wood must be classified on five durability classes (EN 350-1), pointed out by an index (x) calculated from the ratio between percent mass loss of the samples and mass loss of control samples (Scots pine samples) (*table II*).

Table II. Durability classes for the different durability indexes, according to EN 113.

Durability class	Description	Results of laboratory tests (expressed as x*)
1	Very durable	$x \leq 0.15$
2	Durable	$x > 0.15$ but ≤ 0.30
3	Moderately durable	$x > 0.30$ but ≤ 0.60
4	Slightly durable	$x > 0.60$ but ≤ 0.90
5	Not durable	$x > 0.90$

* value x = average corrected mass loss of test specimens / average mass loss of reference specimens.

3.3. Methods for physical and mechanical tests

For physical tests, samples were rewetted through vacuum impregnation in demineralised water, over the f.s.p. Density at 12% m.c. and basic density were measured, according to ISO3131.

Before mechanical testing, the samples were stored in controlled environment in order to reach the 12% m.c.

The mechanical tests were performed on a 20 tons hydraulic computer controlled universal testing machine. The list of performed tests is on *table I*.

The bending MOE were determined through a dynamic test, developed by Cirad Forêt (Bing 6.1), on the same samples prepared for the bending MOR test. This method has been chosen because it is very quick; furthermore, several authors (e.g. [2]) demonstrated its reliability, particularly on clear samples.

4. RESULTS

4.1. Natural durability

The mean mass loss on all the *Pinus sylvestris* reference specimens was 38.87% for *Gloeophyllum trabeum*, 41.80% for *Coniophora puteana*, 16.21% for *Poria placenta.*

The results about natural durability against fungi of Atlas cedar wood will be detailed according to each testing fungal species. It must be noticed that no other durability results about Atlas cedar wood are available in literature.

– *Gloeophyllum trabeum*: the average mass loss of sapwood is 28% and the durability index is 0.72 (class 4, slightly durable). Heartwood showed a mass loss of 0.5% and a durability index 0.01 (class 1, very durable).

– *Poria placenta*: the Atlas cedar wood gave the best results against this fungus: the sapwood showed a mean mass loss of 10% and a durability index of 0.61 (class 4, slightly durable), as for previous fungus, while heartwood had a mass loss of 1.1% and a durability index of 0.06 (class 1, very durable).

– *Coniophora puteana*: the average mass loss of the sapwood is 39%, the highest, with a durability index of 0.93 (class 5, not durable). The heartwood zone gave good results: the average mass loss is 1.0%, with a durability index 0.02 (class 1, very durable).

The mass losses of heartwood for each tree are reported on *table III*.

Table III. Mean mass loss (%) for each cedar tree and for each fungi test; standard deviation on brackets.

Tree n°	Mass loss (%) for each fungi test		
	Gloeophyllum trabeum	*Poria placenta*	*Coniophora puteana*
1	0.58 (0.18)	0 (0)	0.26 (0.16)
2	0.9 (0.91)	0.65 (0.08)	0.35 (0.15)
3	1.15 (0.58)	1.09 (0.2)	0.40 (0.19)
4	0.21 (0.1)	1.43 (1.11)	0.8 (0.05)
5	0 (0)	3.14 (0.63)	0.05 (0.1)
6	0.35 (2.92)	0 (0)	3.9 (0.3)

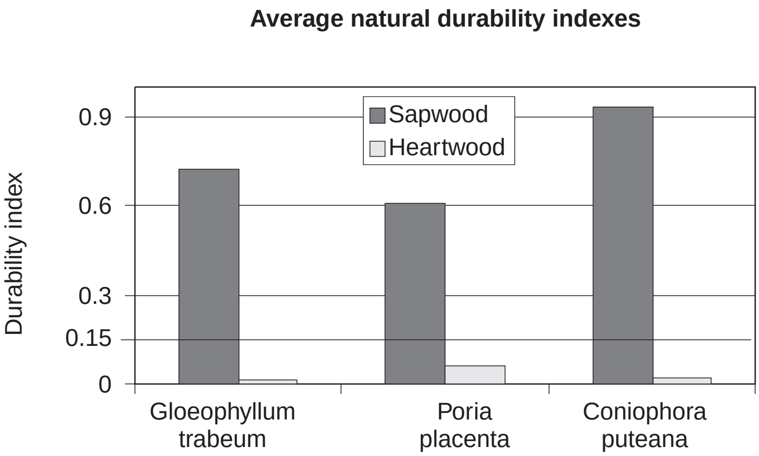

Figure 1. Average natural durability indexes of Atlas cedar heartwood and sapwood to the three fungal agents. The 0.15 level indicates the limit value for the class 1.

The percent mass loss of the sapwood is different in a very significant way from heartwood mass loss (see *figure 1*): both the near the cambium and near the heartwood regions of sapwood have a durability index included among the class 4 and 5 ("slightly durable" and "not durable"); while the heartwood samples had neglectable percent mass loss with the three fungi, so that it can be considered as "very durable".

4.2. Physical and mechanical characteristics

The results of physical and mechanical characterisation of Atlas cedar wood from Southern Italy are summarised on *table IV*. *Table V* refers about physical and mechanical properties found on the same species by other authors.

From the physical point of view the most important points are the following:

The wood density is quite similar to that found by other Authors on the same species [6, 8, 3] and it seems quite high, even if the station allowed good increments and wide growth rings (measured average width was about 4 mm) [5].

Despite that, measured shrinkages were low; the ratio Tangential/Radial shrinkage underlines that this wood is stable and it would allow the opening of very small radial cracks. Also the shrinkage values are on the same line as the literature data [3, 4, 5, 8].

From the statistical analysis we can underline the presence of standard deviation values rather high. This is due to the presence of anomalous results from one tree, giving uniformly low shrinkage values (mean volumetric shrinkage = 8.95%), while the values obtained from each tree were uniform.

Table IV. Main average results of the physical and mechanical characterisation (ρ_y = basic density; ρ_{12} = density at 12% m.c.; β rad = radial shrinkage; β tang = tangential shrinkage; T/R = ratio tangential/radial shrinkages; β vol = volumetric shrinkage; E = bending MOE; σ_b = bending MOR; σ_c = parallel compression strength; τ = shear strength).

	ρ_y (g cm^{-3})	ρ_{12} (g cm^{-3})	β rad (%)	β tang (%)	T/R	β vol (%)	E (MPa)	σ_b (MPa)	σ_c (MPa)	τ (MPa)
N° of specimens	76	76	76	76	76	76	74	66	73	68
Mean	0.44	0.53	4.77	6.35	1.35	11.26	10 101	94	48.8	13.6
Standard deviation	0.03	0.04	0.69	0.84	0.16	1.16	2 439	13	5.2	1.7
Variation Coefficient (%)	6.28	6.80	14.47	13.17	11.94	10.34	24.14	14.03	10.73	12.78

Table V. Comparison between the different results obtained by different Authors from physical and mechanical characterisation of Atlas cedar wood. A = De Philippis 1937 (Central Italy) [1]; B = Ellatifi 1994 (Southern France) [3]; C = Varga- F., né-Foldi 1998 (Hungary) [5]; D = Boudy 1950 (Northern Africa) [1]; E = Oramas 1964 (Spain) [1]; F = Southern Italy (this paper).

	Density ($g\ cm^{-3}$)	Total shrinkage (%)	T/R	Ring width (mm)	Compression strength (MPa)	Bending strength (MPa)	Bending MOE (MPa)
A	0.531 (15% m.c.)	11.2	–	–	43.2	123.3	–
B	0.580 (15% m.c.)	–	–	2.1	55.5	68.6	9 467
C	0.529 (12% m.c.)	11.01	1.24	–	47.1	64.4	–
D	0.40–0.70 (15% m.c.)	10–16	–	–	30.6–61.2	35.7–112.1	–
E	0.559 (15% m.c.)	12	–	–	51	105.1	–
F	0.527 (12% m.c.)	11.3	1.35	3.8	48.8	94	10 101

The mechanical characteristics are rather good and the ratio of static quality (ratio between parallel compression strength and density at 12% m.c.) of this wood is one of the best, compared to that of the most Italian utilised softwood (Norway spruce) and to that of other species planted in Italy [1].

Bending and shear strength allow the classification of this wood into the "strong" grade [9], while taking into account the compression strength and the bending MOE, the Atlas cedar wood is on average strong and yielding.

5. DISCUSSION AND CONCLUSIONS

As for all the softwood species, the sapwood of Atlas cedar wood showed a low durability and, disregarding their radial position, all the samples are within the "not durable" class.

Whereas in the heartwood the durability trials made against *Poria placenta* gave highest mass loss, within the "very durable" class. This result is confirmed not only by the analysis of the general data, but also considering the different examined trees and the radial position of the heartwood. This last result is probably due to the young age of the trees (about 30 years old), thus we cannot find difference in heartwood durability, caused by the age of duramification.

The physical and mechanical features have shown a wood characterised by rather good values, highlighting that the wood is very stable and that the structural efficiency of the Atlas cedar wood is high, compared to that of the most utilised softwood species for structural purposes.

From first trials the Atlas cedar wood seems to be suitable for packing and structures, even if its heartwood high durability and dimensional stability could allow, in case of high quality wood, the use for window frames.

The species shows a good ecological adaptability and the quality of the standing trees in artificial plantation seems to be better compared to other softwoods at present used in Southern Italy, such as *Pinus halepensis*, *Pinus radiata* and *Pinus insignis*, even if no cultural operations, like thinnings or pruning were made.

All those characteristics could suggest a larger diffusion of Atlas cedar in artificial plants in Central and Southern Italy, particularly in Sicily, where not only the protection function could be achieved, but also the productive one. About that see also [7]: "Probably within one or two centuries the cedar woodland will be a diffuse landscape in Mediterranean France: a return to the past, since the cedar forests were very important in those regions before the Quaternary glaciations."

Further studies on the heartwood percentage in mature trees, on the impregnability of the sapwood and on durability in ground contact will improve the knowledge of that wood and suggest larger utilisations of Atlas cedar wood.

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