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Timber Properties of Minor Conifer Species

A report to Forestry Commission England

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Introduction

There are increasing concerns that the limited range of species currently used in commercial conifer plantations has exposed UK forests to heightened risks in the face of climate change. FC England is considering wide-scale planting of a number of species that have hitherto only been present in small stands, forest gardens or as specimen trees. For many of these “minor” species there is limited knowledge of the wood properties and product performance of their timber. Concern has been expressed within the wood processing sector that planting of these species is taking place in the absence of reliable information about the timber that will be produced when they are grown in UK conditions.

In this short report we present available information relating to the mechanical properties and durability of some of the minor conifer species that are currently being considered for plantations in England. In order to support interpretation of these data we have included a brief overview of softwood timber performance criteria.

For many species data availability is limited, and there is rarely clear information about the growing location of sample material, or the age of trees from which it was cut. For each species considered we have provided a brief commentary on the available data.

Timber performance criteria

The current softwood market in the UK is dominated by Sitka spruce, with large sawmills investing millions of pounds in new sawing and grading machinery which are designed to maximise throughput and return. The most valuable section of the market for softwoods in the UK is currently in construction. For structural applications (e.g. timber frames, floors, roof trusses and production of laminated elements), mechanical properties are generally the key performance criteria, with drying distortion also an important factor. For external applications in construction (e.g. cladding) natural durability and treatability are normally the key consideration, together with appearance characteristics. In order to be used as an engineering material in new buildings and to conform to European Standards, timber is strength graded on a strict set of criteria.

Timber Mechanical Properties

In Europe softwood timber for structural use is usually graded into strength classes, C14 – C50 EN338 (CEN, 2009), in accordance with the specifications ofEN14081. The three properties which determine the strength class which a population of timber will be assigned to are stiffness, strength and wood density, all assessed on structural sized pieces of timber which will contain defects such as knots and grain deviation. The strength and stiffness normally relate to bending of the timber, although tension grades also exist for manufacture of laminated products. Stiffness, or Modulus of Elasticity (MoE) is the term used to describe the linear relationship between stress (force applied) and strain (deflection), up to the proportional limit. The more stress that is required to achieve a given deflection, the stiffer a material is. Modulus of Rupture (MoR) is the bending strength of a material. It is defined as the maximum load at the time of failure in a bending test. Wood density is the mass of wood per unit volume, often quoted as basic density which is oven dry mass of wood/green volume, although the EN338 densities are mass / volume at 12% moisture content.

The characteristic values of each property required for strength classes C14 – C30 are shown in Table 1. Allocation of timber to a strength class is either through a process of visual inspection (visual strength grading) or by assessment with one of a number of machines (machine strength grading) which measure properties related to timber strength by bending, x-ray scanning or measurement of stress wave velocity. Machine strength grading of structural timber is the norm in softwood sawmills in the UK.

Table 1: Characteristic values of selected mechanical properties for strength classes C14-C24 (from EN338). Values for bending strength and density refer to the lower 5th percentile, while values for modulus of elasticity refer to the mean.

Property	Characteristic property values for each strength class							
	14	**16**	**18**	**20**	**22**	**24**	**27**	**30**
Bending strength (N mm^{-2})	14	16	18	20	22	24	27	30
Modulus of Elasticity (kN mm^{-2})	7	8	9	9.5	10	11	11.5	12
Density (kg m^{-3})	290	310	320	330	340	350	370	380

Much of the mechanical properties data that are available for minor conifer species relates not to the structural sized pieces tested when timber is assigned to a strength class, but to small clear samples. These standard, defect-free test pieces allow comparisons of mechanical properties to be made between species, but do not allow allocation to a strength class. Small clear samples represent the best mechanical performance of a given species as they exclude defects by their very definition. When structural sized samples are tested there is normally a reduction in mechanical performance due to defects in the larger pieces, e.g. knots will lower MoR values. This difference between small clear properties and structural size properties will vary from species to species, and growth area, due to the varying severity of defects. In the mechanical data for minor conifer species presented here we have identified whether the data originate from structural-sized or small clear samples.

In addition to the data from published literature that we have collated here, Dr Dan Ridley-Ellis has developed a model to give an estimate of possible strength class on the basis of data from small clear samples: see Appendix 1.

Natural durability

Where available we have provided information relating to the natural durability of the minor conifer species covered in this report. Moore (2011), provides a clear description of the importance of timber's natural durability and how this is classified:

"Natural durability is defined in EN350-1 (CEN, 1994) as 'the inherent resistance of wood to attack by wood-destroying organisms', with biological attack from fungi and insects considered the most important. The climate in Great Britain means that the main agents of biodegradation are various species of fungi, rather than insects. Natural durability of untreated wood to wood-destroying fungi is determined either from ground contact trials (sometimes referred to as 'graveyard trials') or from laboratory tests using the basidiomycete fungi (CEN, 1994; Råberg et al., 2005). Based on the results of these tests, wood from a particular species is assigned to one of five natural durability classes, 1–5, where 1 is very durable and 5 is not durable (Table 2). This assignment to classes is on the basis of the average life of the test stakes relative to the average service life of the most durable set of reference stakes for field tests, and on the basis of mass loss relative to that of the reference specimens for laboratory tests. In both types of test the reference specimens are Scots pine sapwood."

Note: Durability classes refer to heartwood: all sapwood is classed as not durable.

Table 2 Classes of natural durability of wood to fungal attack (after EN350-1; CEN, 1994a).

Durability Class	Description
1	very durable
2	durable
3	moderately durable
4	slightly durable
5	not durable

As described by Davies (2009) the requirement for natural durability depends on the microclimate (use class) in which the timber is located. Use classes 1-5 are defined in EN 335-1 (CEN, 2006), Table 3.

Table 3 Use classes for timber (After EN 335-1 & 335-2)

Use Class	Moisture condition
1	Timber inside buildings. Moisture content permanently below 20%
2	Timber inside buildings but exposed to condensation or leaks. Moisture content occasionally above 20%
3	External timber out of ground contact. Moisture content frequently above 20%.
4	In ground contact or fresh water. Moisture content permanently above 20%.
5	In sea water, moisture content permanently above 20%.

EN460 gives guidance on the level of natural durability or preservative treatment required for resistance against fungal decay in different use classes (Table 4).

Table 4: EN460 Natural durability of preservative treatment needed for resistance against fungal decay (after Davies, 2009).

Durability class	1 Very Durable	2 Durable	3 Moderately durable	4 Slightly durable	5 Not durable
Use class					
1: Above ground, covered, dry					
2: Above ground, covered, risk of wetting					
3: Above ground, not covered, period of wetting					
4: in ground or fresh water					
5: In sea water					

KEY

	In these conditions natural durability is always sufficient and there is no requirement for preservative treatment
	Natural durability is normally sufficient in these conditions but for certain uses where condensation is likely preservative treatment is advised
	Natural durability may be sufficient in these conditions, but depending on the wood species and end-use preservative treatment may be needed
	Preservative treatment is normally advised in these conditions but natural durability may be sufficient in some cases
	Preservative treatment is always necessary in these conditions

Species Descriptions

Table 5 shows available wood properties data from the published literature for minor conifer species currently under consideration for diversifying the public forest estate in England. Note that much of the data presented here is from a very small sample size.

In addition to data for MOE, MOR and specific gravity (wood density), we have included data relating to hardness. Hardness tests for wood are usually carried out using the Janka method which measures the resistance of the wood to denting. It measures the force required to embed an 11.28 mm steel ball into the wood to half of the ball's diameter. Testing the suitability of a species for flooring applications is the most common use of the Janka testing method.

Table 5 Wood properties data for minor conifer species (Note: Specific gravity, SG, is the ratio of wood density to the density of pure water at 4°C. It is numerically equivalent to basic density, i.e. SG of 0.34 = basic density of 340 kg m^{-3})

Species	Specific gravity	MoE	MoR	Side Hardness	Number of samples	Sizes	Region	Reference for mechanical properties data	Natural durability class
		kN/mm^2	N/mm^2	N					
Sitka spruce *Picea sitchensi*	0.34	8.1	67	2140	54 trees and 50 joists	Small clears + Structural	UK	Lavers, 2002	4 to 5
Sitka spruce *Picea sitchens*	0.39	10.5	74	2200	14 trees	Small clears	Canada	Lavers, 2002	
Norway spruce *Picea abies*	0.35	8.5	66	2000	188 trees	Small clears	UK	Lavers, 2002	4
Serbian spruce *Picea omorika*	0.36	7.6	72	2710	5 trees	Small clears	UK	Lavers, 2002	
Oriental spruce *Picea orientalis*	0.52	8.2			4 trees	Small clears	Turkey	Togay, 2009	
Hybrid larch *Larix eurolepis*	0.41	8.5	77	3160	5 trees	Small clears	UK	Lavers, 2002	
Japanese larch *Larix kaempferi*	0.43	8.3	83	2890	59 trees and 30 joists	Small clears + Structural	UK	Lavers, 2002	
European larch *Larix decidua*	0.48	9.9	92	3650	77 trees	Small clears	UK	Lavers, 2002	3 to 4
Douglas fir *Pseudotsuga menziesii*	0.49	12.7	93	2980	78 trees	Small clears	Canada	Lavers, 2002	3 to 4
Douglas fir *Pseudotsuga menziesii*	0.36	11.3	69			Small clears	Canada	Wood Handbook	
- Coastal	0.48	13.4	85	3200		Small clears	U.S.	Wood Handbook	
- Interior west	0.50	12.6	87	2900		Small clears	U.S.	Wood Handbook	
- Interior north	0.48	12.3	90	2700		Small clears	U.S.	Wood Handbook	
- Interior south	0.46	10.3	82	2300		Small clears	U.S.	Wood Handbook	
- UK Grown	0.44	10.5	91	3420	54 trees	Small clears	UK	Lavers, 2002	
Grand fir *Abies grandis*	0.37	10.8	61	2200		Small clears	U.S.	Wood Handbook	
Noble fir *Abies procera*	0.39	11.9	74	1800		Small clears	U.S.	Wood Handbook	

Species	SG	MoE	MoR	Side Hardness	Number of samples	Sizes	Region	Reference	Natural durability class
		kN/mm^2	N/mm^2	N					
Pacific silver fir *Abies amabilis*	0.36	11.3	69			Small clears	Canada	Wood Handbook	
European silver fir *Abies alba*	0.40	9.8	79	2850	15 trees	Small clears	UK	Lavers, 2002	4
European silver fir *Abies alba*	0.38	8.8	77	2490	28 joists	Structural	Yugoslavia	Lavers, 2002	
Nordmann fir *Abies nordmanniana*									
Scots pine *Pinus sylvestris*	0.46	10.0	89	2980	61 trees	Small clears	UK	Lavers, 2002	3 to 4
Lodgepole pine *Pinus contorta*	0.40	10.9	76			Small clears	Canada	Wood Handbook	3 to 4
Lodgepole pine *Pinus contorta*	0.42	8.1	79	2940	25 trees	Small clears	UK	Lavers, 2002	
Maritime pine *Pinus pinaster* - UK	0.43	8.9	77	2670	7 trees	Small clears	UK	Lavers, 2002	
- Atlantic	0.52	10.0	38		351 joists	Structural	Spain	Fernandez-Golfin, 1996	
- Mediteranean	0.53	9.1	36		175 joists	Structural	Spain	Fernandez-Golfin, 1996	
Macedonian pine *Pinus peuce*	0.35	4.8	52			Small clears	UK	Lines, 1985	
Western red cedar *Thuja plicata*	0.32	7.7	52	1600		Small clears	U.S.	Wood Handbook	
Western red cedar *Thuja plicata*	0.33	7.0	65	2000	10 trees	Small clears	UK	Lavers, 2002	3
Western hemlock *Tsuga heterophylla*	0.38	8.0	76	2580	15 trees	Small clears	UK	Lavers, 2002	4
Western hemlock *Tsuga heterophylla*	0.45	11.3	78	2400		Small clears	U.S.	Wood Handbook	
Western hemlock *Tsuga heterophylla*	0.41	12.3	81			Small clears	Canada	Wood Handbook	
Leyland cypress *Cupressocyparis leylandii*	0.40	5.9	77	2980	3 trees	Small clears	UK	Lavers, 2002	

Species – English name	**SG**	**MoE**	**MoR**	**Side Hardness**	**Number of samples**	**Sizes**	**Region**	**Reference**	**Natural durability class**
		kN/mm^2	N/mm^2	N					
Lawson cypress *Chamaeccyparis lawsoniana*	0.37	5.4	68	2620	10 trees	Small clears	UK	Lavers, 2002	
Atlas cedar *Cedrus atlantica*	0.44	10.1	94		6 trees	Small clears	Italy	Brunetti et al, 2001	
Japanese incense cedar *Cryptomeria japonica*	0.50	9.6	53			Structural	Taiwan	Wang & Ko, 1998	5
Coast redwood *Sequoia sempervirens*	0.35	7.6	54	1900		Small clears	U.S.	Wood Handbook	
Wellingtonia - old growth *Sequoiadendron giganteum*	0.30	4.7	40				U.S.	Piirto & Wilcox, 1981	
Wellingtonia - young growth *Sequoiadendron giganteum*	0.35	8.9	64				U.S.	Piirto & Wilcox, 1981	

Sitka spruce - *Picea sitchensis*

The values for MoE and MoR presented in Lavers (2002) are in line with values found from extensive recent research carried out in the UK (see Moore, 2011). Sitka spruce grown in the UK regularly meets the C16 grade which is the minimum for use in construction. It is also possible to grade out a proportion of C24 grade timber from the UK Sitka spruce resource, but this has not generally been considered economic by UK sawmills.

Norway spruce - *Picea abies*

Norway spruce timber is very similar to that of Sitka spruce and the data shown here supports this. A problem associated with Norway spruce timber is a high incidence of spiral grain, which can often be seen on the standing tree. Spiral grain is likely to lead to distortion in timber during kiln drying. The data here are from test on small clear samples from 188 trees.

Serbian spruce - *Picea omorika*

The values for Serbian spruce are derived from small clears testing on only five trees, which are likely to have come from one site, although we cannot say that with certainty. In its native range the timber from this tree is used for pulping in the paper industry and also as construction material.

Oriental spruce - *Picea orientalis*

Data for this species are from small clears came from only 4 trees which were grown in Turkey. We have no available data relating to trees grown in the UK.

Douglas-fir - *Pseudotsuga menziesii*

Douglas-fir is an extremely important commercial species for construction and cladding markets in its native range and also increasingly across Europe. The values presented here demonstrate some of the variation in properties in material growing in the US and Canada, as well as data from 54 trees grown in the UK. In a recent PhD study of Douglas fir timber grown in the south-west of Britain, it was estimated that the strength grade of the timber tested ranged from C16 for material cut from the juvenile core of faster grown trees to C27 for material cut from the mature wood of slower grown trees (Bawcombe, 2012). Initial results from further study at Edinburgh Napier University found that Douglas fir timber from trees growing in central Scotland achieved C18 during a simulated grading study.

European silver fir - *Abies alba*

There are extensive data from studies across Europe relating to the properties and uses of the timber from this species. The values presented here show that both MoE and MoR are significantly higher than the values for Sitka spruce. The values from the structural pieces tested from the former Yugoslavia are lower but will include the usual defects.

When managed correctly, the timber from this species can be used for internal joinery and also in larger construction sections.

Maritime pine - *Pinus pinaster*

The structural pieces grown in Spain from two different provenances are difficult to compare to the small clears grown in the UK, the origin of which is unknown and is only based on 7 trees. Climatic, genetic and silvicultural differences exist between these datasets further confounding the difficulties. However, under UK conditions the timber could be compared to that of lodgepole pine, although as the species is susceptible to DNB its potential seems limited at present. In Europe it is used extensively in the production of furniture, flooring and value-added products such as laminated veneer lumber (LVL).

Macedonian pine - *Pinus peuce*

There is little information available on the timber from this species. The values here are based on data from small clears but the number of samples is unknown.

Western red cedar - *Thuja plicata*

Data are presented from both the US and from 10 trees grown in the UK. This species is used extensively in external applications, particularly cladding.

Western hemlock - *Tsuga heterophylla*

The values presented for UK data (small clears from 15 trees) suggest that western hemlock grown in the UK has a lower wood density and lower stiffness than material grown in the US and Canada. However, from the available data it is impossible to determine whether this difference is due to differences in sample age (e.g. greater proportion of juvenile wood in the UK sample than in the N. American samples), or if there is an actual difference in wood properties when samples of a similar age are compared. The timber from this species is used in construction and external applications.

Leyland cypress - *Cupressocyparis leylandii*

These values are based on a small clears testing from a very small number of trees. The high MoR value and low MoE value may not be representative. There is some evidence to suggest that the heartwood is moderately durable.

Atlas cedar - *Cedrus atlantica*

This species is being used extensively to re-forest large areas of Italy. The relatively high MoE and MoR values presented here are encouraging but are based on small clears on a sample of only 6 trees so caution should be used in their interpretation. This is the primary source of construction timber across Morocco.

Japanese incense cedar - *Cryptomeria japonica*

The values presented here are based on an unknown sample size of structural pieces which were grown in Taiwan. This species is widely used in construction in Japan.

Coast redwood - *Sequoia sempervirens*

These values are based on an unknown number of small clear specimens from the US. Timber from this species is used in north America in construction and external applications such as cladding.

Wellingtonia - *Sequoiadendron giganteum*

The data presented are from a review of studies of young and old growth Wellingtonia in California. It is worth noting that “young growth” may refer to trees aged 60-80 yeasr at the time of felling.

Possible further work

The information presented here is based on a rapid collation of available data. It is possible that further data in the literature could be tracked down with more time. A PhD Project at Edinburgh Napier University, (funded by the Scottish Forestry Trust and the Forestry Commission) will evaluate the wood properties and structural timber performance of Norway spruce, western hemlock, western red cedar and noble fir: this study is likely to be completed in 2016, but some preliminary results may be available earlier. In order to assess the wood properties and potential performance of some of the other minor conifer species of interest, and to determine how these might vary between UK sites, additional research would have to be commissioned and funded.

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Appendix 1. Strength class estimation model

Dr Dan Ridley-Ellis (Edinburgh Napier University's Forest Products Research Institute) has developed a model for estimating Strength Grade from small clear data. The results must be viewed with extreme caution as they are based on a number of assumptions, for which we have no real supporting evidence:

a) An estimate is made for wood density, MoR (strength) and MoE (stiffness) of structural sized pieces, from the small clears data. The conversion for wood density comes from a published standard, those for MoR and MoE are based on Sitka spruce data held by Napier. The relationship between values for small clears and structural sized pieces will vary, and we have no data for the species in question.

b) The lower 5th percentile values of MoR and wood density for structural pieces (characteristic values required in grading) are estimated from the predicted mean values, based on an assumed variation within the population: again we have no data for the species in question.

c) The grade estimate is based on the very small sample sizes available in the published data: normally a much larger sample from across a geographic region (growing area) would be required to assign timber to a strength grade. We have no knowledge about the origin of the samples in terms of tree age, growing location.

Bearing in mind these reservations, we have applied the model to the UK small clears data from Table 5 and the results are given in Table 6.

If the estimated values for structural sized timber are compared with the characteristic property values given for the different strength grades in Table 1 it can be seen that wood stiffness, MoE, is the limiting factor for each species in terms of the grade it can be assigned to. Some of the species do not make the minimum requirements for the lowest softwood grade (C14), on the basis of these data and this model prediction.

Table 6 Estimated strength grade and structural sized timber properties, based on small clear data from the UK

Species	Input small clears data (from Table 5)			Output data from model – estimates for structural sized timber. NB: estimates based on small amounts of data and the assumptions given above			
	Specific Gravity	Modulus of Elasticity (kN/mm^2)	Modulus of Rupture (N/mm^2)	Modulus of Elasticity: Mean (kN/mm^2)	Modulus of Rupture: 5th Percentile (N/mm^2)	Wood density at 12% moisture content: 5th percentile (Kg/m^3)	Estimated strength grade on basis of predicted wood property values
Norway spruce *Picea abies*	0.35	8.5	66	8.08	22.1	344	C16
Serbian spruce *Picea omorika*	0.36	7.6	72	7.22	24.16	354	C14
Hybrid larch *Larix eurolepis*	0.41	8.5	77	8.08	25.83	403	C16
European larch *Larix decidua*	0.48	9.9	92	9.41	30.87	472	C18
Douglas fir *Pseudotsuga menziesii*	0.44	10.5	91	9.98	30.53	432	C20
European silver fir *Abies alba*	0.40	9.8	78	9.3	26.5	393	C18
Scots pine *Pinus sylvestris*	0.43	10.0	89	9.5	29.86	452	C18
Maritime pine *Pinus pinaster*	0.43	8.9	77	8.46	25.83	423	C16
Macedonian pine *Pinus peuce*	0.35	4.8	52	4.56	17.45	344	-
Western red cedar *Thuja plicata*	0.33	7.0	65	6.65	21.81	324	-
Western hemlock *Tsuga heterophylla*	0.38	8.0	76	7.6	25.5	373	C14
Leyland cypress *Cupressocyparis leylandii*	0.4	5.9	77	5.61	25.8	393	-
Lawson cypress *Chamaeccyparis lawsoniana*	0.37	5.4	68	5.13	22.8	364	-