Bending and compression properties of small diameter round timber

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ABSTRACT

Objective of the completed European project was to find new uses for small diameter round timber harvested in forest thinning. The project included a wide range of studies: economy of harvesting, drying technology, development of structures and connections, and demonstration of feasible use of round small diameter wood. The mechanical properties are of special interest because the material includes a large portion of juvenile wood. This paper reports on the bending and compression test results and gives a suggestion for visual strength grading. The material includes Scots pine, Norway spruce, Sitka spruce and larch. Results show that strength of small diameter round timber is high corresponding to the highest quality sawn timber. There are however limits in growth rate and knot dimensions which have to be respected when used in load bearing structures. The effect of juvenile wood is observed only on compression behaviour in part of the material. The project has demonstrated that small diameter timber can be used in load bearing structures, and it is in fact a strong material. Simple visual rules are adequate for strength grading. The results give a basis to start an international standardisation for structural use of small diameter round timber.

INTRODUCTION

In many countries there is a surplus of small diameter (8-15 cm) round timber, which is harvested in forest thinning. A joint European (FAIR) project was started 1996 in order to develop the use of small diameter round timber in construction. The overall objective of the research was to develop structural systems in which small diameter round timber can be used and thereby create a new market for small diameter round-wood. VTT was co-ordinating the project and the other participants were Agricultural Research Centre of Finland (MTT), Technological University Delft, University of Surrey from the UK, Lekopa Oy from Finland, Universität für Bodenkultur (BOKU) from Austria, and Centre Technique du Bois et de l'Ameublement (CTBA) from France.

The work has covered a wide range of aspects, from availability of the material to design of the structures:

- availability, dimensions and quality of conifers harvested in forest thinning
- cost of harvesting and woodworking
- comparison of drying methods: seasoning, warm-temperature and high-temperature kiln-drying
- improving durability
- strength of round small-diameter conifers
- potential types of structures to be built from round timber
- new mechanical joints.

The main results of the project are published in a final report (Ranta-Maunus 1999) and several other publications have been produced. It is known from past experience that bending strength of round timber is fairly high. In Finnish standards, a characteristic bending strength of 30 MPa has been adopted for pine and spruce round timber, if no other information is available. However, small diameter (80 to 150 mm) round wood could have considerably lower strength than mature logs, because it is, to large extent, juvenile wood. On the other hand, the commonly accepted size effect suggests that small diameter wood should have higher strength than large diameter timber. These conflicting arguments provide the background for the strength testing carried out in this project.

In this paper a summary of strength testing in bending and compression is presented. More detailed information can be found in several other papers listed in references. Effects of age and moisture content on mechanical properties and twisting of Finnish round and sawn pine (Pinus sylvestris) and spruce (Picea abies) are discussed in this conference (Boren 2000).

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MATERIALS AND METHODS

The quality of the tested timber was characterized by measurements. Such variables were recorded that could possibly affect the strength. These included the diameter, density, moisture content and several knot-related parameters. The following notations were used for the variables:

- *a* = age (years), measured at or close to the failure point
- *d* = diameter of the specimen (mm), measured at or close to the failure point
- *ks* = knot sum (mm), measured at or close to the failure point
- *ks/c* = KAR= knot sum per circumference (%), measured at or close to the failure point
- *ks/d* = knot sum per diameter (%), measured at or close to the failure point
- *mk* = max. knot (mm), measured at or close to the failure point; measurement method is shown in Figure 3.13.
- ρ_{12} = density at 12 % moisture content (kg/m^3) at or close to the failure point
- $\rho_{12,\,0.05}$ = 5-percentile value of the sample for density at 12 % moisture content (kg/m^3)
- *r* = ring width (mm), measured at or close to the failure point
- *t* = average taper (mm/m), tapering (to measure conical shape of specimen) only for bending specimens
- *u* = moisture content, mass of water per dry mass (%), measured at or close to the failure point

For the calculated strength and stiffness values, the notations are used as follows:

- $E_{c,\,0}$ = modulus of elasticity in compression parallel to the grain (kN/mm^2)
- E_m = modulus of elasticity in bending (kN/mm^2)
- $f_{c,\,0}$ = compression strength parallel to the grain (N/mm^2)
- $f_{c,\,0,\,0.05}$ = 5-percentile value of the sample for compression strength parallel to the grain (N/mm^2)
- f_m = bending strength (N/mm^2)
- $f_{m,\,0.05}$ = 5-percentile value of the sample for the bending strength (N/mm^2)
- $f_{m,\,k}$ = characteristic value of the population for the bending strength (N/mm^2).

Table 1. Means and standard deviations of the property values in round material.

Bending material Mean / st. d.						
	Austria	Finland		Holland	UK	
	spruce	pine	spruce	larch	pine	Sitka
N	85	175	200	185	100	100
a		20 / 4	28 / 9	41 / 7	33 / 6	19 / 4
d	134 / 20	125 / 22	113 / 21	121 / 16	529 / 41	126 / 12
ks	20 / 13	76 / 26	47 / 25	28 / 17	75 / 39	77 / 27
ks/d	16 / 10	62 / 20	41 / 19	23 / 15	60 / 31	62 / 22
mk		19 / 6	13 / 6	17 / 7	23 / 13	19 / 5
ρ_{12}	450 / 49	470 / 38	434 / 67	577 / 46	529 / 41	478 / 40
r		3.3 / 0.7	2.3 / 1	2.1 / 0.6	2.0 / 0.4	3.7 / 0.9
t		4 / 4	3 / 2	6 / 2	3 / 1	3 / 1
u		15.9 / 3.2	15.6 / 2.3	14.8 / 0.9	18.9 / 1.9	18.3 / 2.2
Compression material Mean / st. d.						
	Austria	Finland		Holland	UK	
	spruce	pine	spruce	larch	pine	Sitka
N	0	175	200	61	100	100
a		19 / 6	24 / 7	43 / 5	33 / 6	19 / 4
d		117 / 22	107 / 23	118 / 17	126 / 11	124 / 14
ks		80 / 39	52 / 25		57 / 47	73 / 27
ks/d		71 / 37	50 / 21		45 / 37	56 / 27
mk		19 / 6	15 / 6		18 / 15	19 / 6
ρ_{12}		472 / 42	426 / 57	582 / 40	539 / 48	476 / 37
r		3.4 / 1.2	2.4 / 0.9	2.1 / 0.6	2.0 / 0.4	3.7 / 0.9
u		15.3 / 3.7	15.7 / 2.1	14.5 / 0.6	17.3 / 1.8	17.3 / 1.9

Table 1 summarizes the sample sizes (N) and characteristics measured. The test material includes Scots pine (Pinus sylvestris), Norway spruce (Picea abies), Sitka spruce (Picea sitchensis), Douglas fir (Pseudotsuga menziesii F.) and larch (larix kaempferi). For Douglas fir, mainly X-ray measurements were made (Adjanohoun et al 1998), and most of the features in Table 1 are not available.

The cumulative frequencies of the most important physical features for the bending material are illustrated in Figure 1 in order to compare the tree species samples. We observe the variation in the properties both within a species and between the species. Also there are some differences between the bending material and compression material. All these natural variations make it difficult to draw conclusions on the effect of a single variable. Especially, it should be noted that the Finnish spruce material includes a large portion of fast grown, light weight material, which makes the density and ring width distributions atypical. This selection was made on purpose, in order to get the sample representative also for the fast grown spruce.

Bending testing was made using 4-point bending. Both the bending and compression testing method followed EN384 as closely as practical for round timber with conical shape and variable diameters. More details are given in the final report of the project (Ranta-Maunus 1999).

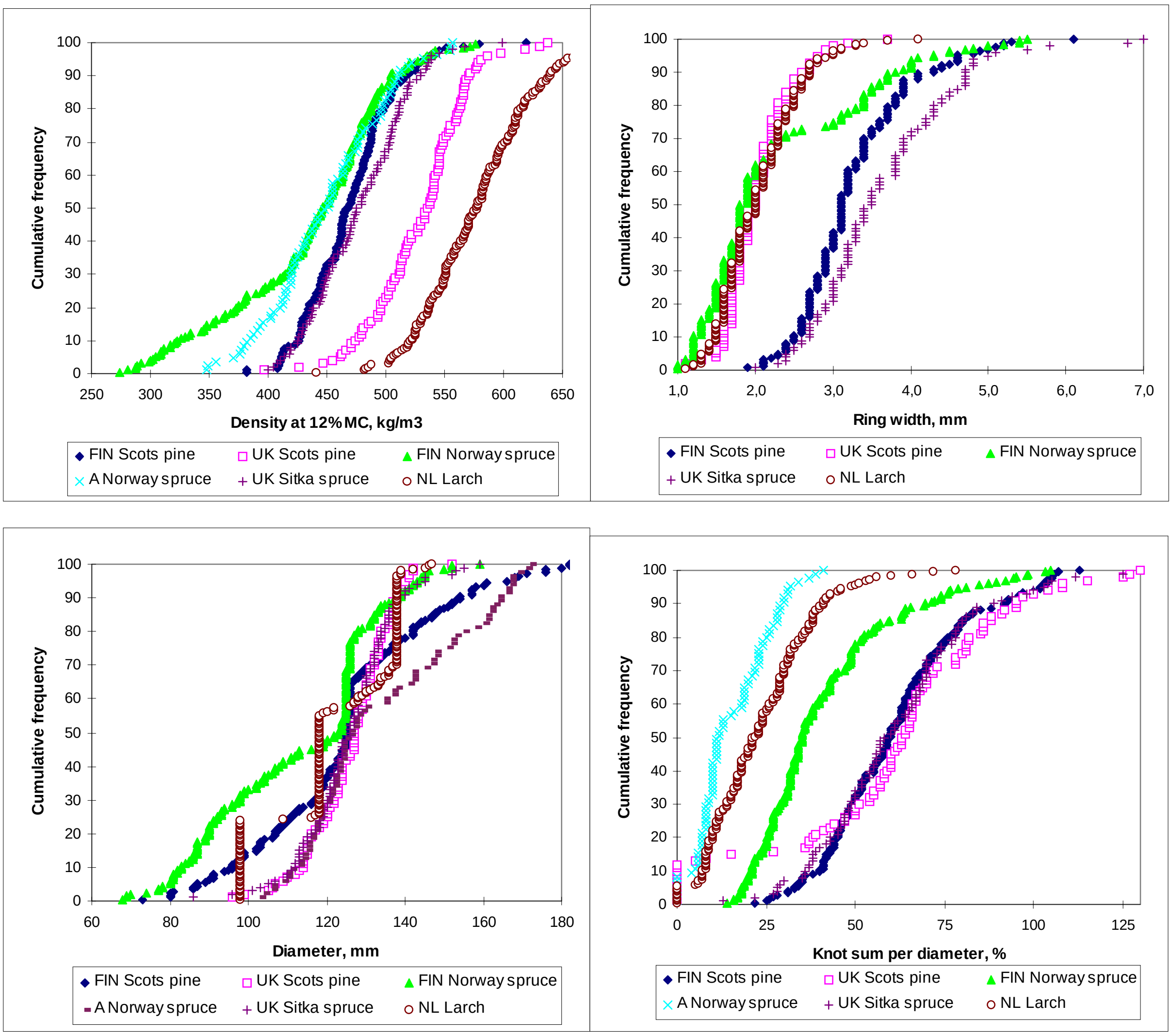

Figure 1. Cumulative frequencies of round bending material by species (A = Austria, FIN = Finland, NL = Netherlands, UK = United Kingdom) .

STRENGTH RESULTS

Overview

The strength and stiffness values obtained in the bending and compression tests are summarized in Table 2, where the mean values and standard deviations are given. Cumulative distributions are shown in Figures 2 and 3. Bending strengths are high, lower 5th percentile ranging from 35 to 60 N/mm^2, all the mean values exceeding 50 N/mm^2. The moisture content in the the tests was mainly in the range from 10 to 20 %. The obtained values were adjusted to 12 % moisture content in accordance with standard EN384: f_c values were adjusted by 3 %, E by 2 %, and density by 0.5% for every percentage point difference in moisture content. No size adjustment was made. The lower fifth percentile values for strength were determined by the ranking method. The lower fifth percentile for density was determined based on normal distribution. The characteristic values, adjusted to 12 % MC, for unsorted material are given in Tables 3 and 4. The strength values are higher than were expected before testing. In particular, bending strength is considerably higher than would be obtained from unsorted sawn timber. The effect of juvenile wood is not seen as a weakening of the material. The exception is the modulus of elasticity in compression. In Figure 3 it is clearly seen that the lowest E-values are below the normal range for Finnish spruce. It is obvious that these specimens have a large proportion of juvenile wood, which has larger effect in compression than in bending where a thin surface layer of mature wood improves bending properties considerably. However, the compression strength is not affected as much as stiffness.

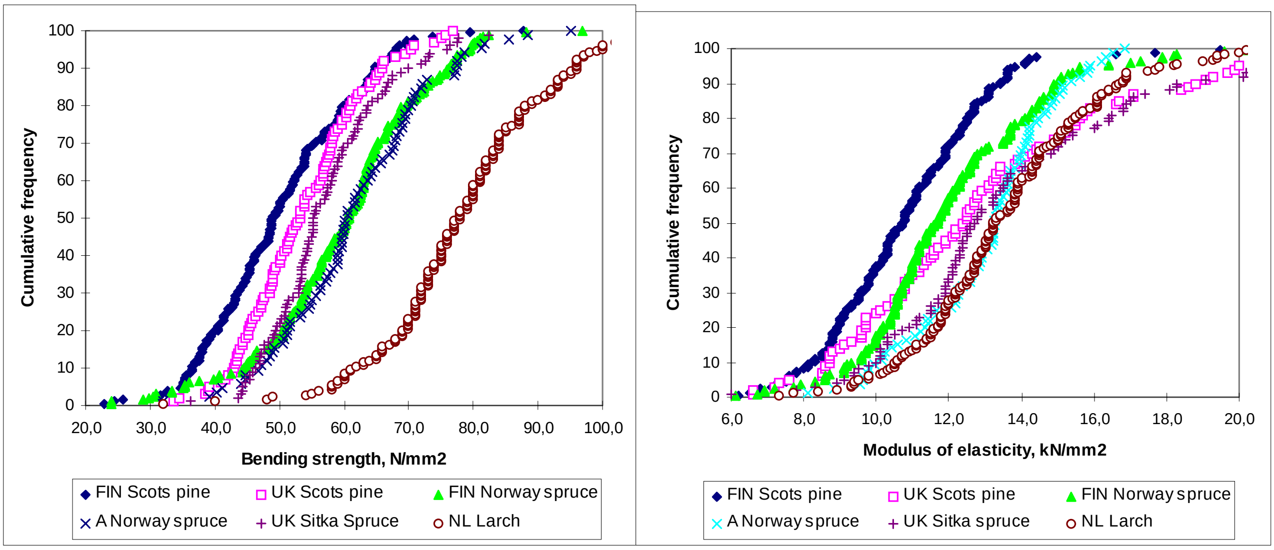

Figure 2. Cumulative frequencies of bending strength and modulus of elasticity by species at test moisture content.

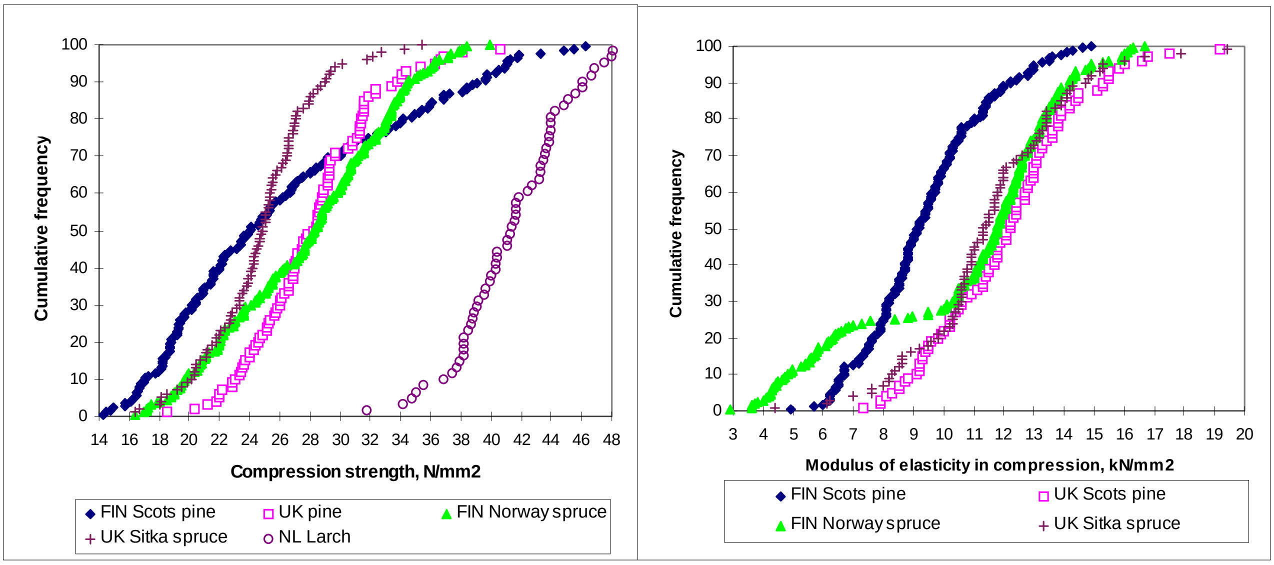

Figure 3. Cumulative frequencies of compression strength and modulus of elasticity by species at test moisture content.

Table 2. Means and standard deviations of bending and compression values of tested round timber at test moisture content.

Species/country		f_m	$f_{c,0}$	E_m	$E_{c,0}$
Scots pine					
	FIN	50.3 / 11.2	26.2 / 8.2	10.9 / 2.4	9.4 / 2.0
	UK	53.8 / 9.3	28.4 / 4.9	13.1 / 4.1	12.2 / 2.8
Norway spruce					
	A[1]	61.7 / 11.6		13.0 / 1.9	
	FIN	59.8 / 12.5	27.8 / 5.6	12.1 / 2.6	10.7 / 3.4
Sitka spruce					
	UK	57.5 / 10.1	24.7 / 3.6	13.9 / 4.4	11.6 / 2.9
Larch					
	NL	78.3 / 12.7	41.4 / 3.7	13.6 / 2.5	
Douglas					
	F	52 / 9.9[2]	33/-	11.1 / 2.4[2]	11.0/-

[1]) Naturally seasoned material
[2]) Cylindrical specimens, d = 120 mm

Table 3. Bending characteristics adjusted to 12 % MC in accordance with EN 384. Size adjustment not used.

Species (country)	Sample size	ρ_{mean} [kg/m³]	ρ_{05} [kg/m³]	$f_{m,mean}$ [N/mm²]	$f_{m,05}$ [N/mm²] by rank	$E_{m,mean}$ [kN/m²]
Scots pine (FIN)	175	470	407	50	35	11.9
Scots pine (UK)	100	529	461	54	39	14.9
Scots pine (FIN+UK)[3)]	250	492	427	52	37	12.9
spruce (FIN)	200	434	323	60	35	12.9
spruce (A) [1)]	143	451	360	61	36	12.9
larch (NL)	178	580	509	85	63	14.3
Douglas (F)[2)]	180	442	367	52	37	11.1
Sitka spruce (UK)	100	478	392	58	44	16.1

[1]) Drying by seasoning
[2]) D = 120 mm, cylindrical, KAR 24 %
[3]) Combined British and Finnish machine rounded.

Table 4. Compression characteristics adjusted to 12 % MC in accordance with EN 384. Size adjustment not used.

Species (country)	Sample size	$f_{c,mean}$ [N/mm²]	$f_{c,05}$ [N/mm²]
Scots pine (FIN)	175	28.0	19.7
Scots pine (UK)	100	32.8	25.9
pine (FIN+UK)	250	30.2	24
spruce (FIN)	200	30.7	20.8
larch (NL)	58	45	38
Douglas (F)	190	33	26
Sitka spruce (UK)	100	28.6	21.7

<u>Statistical analysis</u>

It was analysed, whether the tree species had differences in their mechanical properties when their physical properties were similar. The multipliers of the regression models are summarized in Table 5. The models for E_m and f_m cover larch, Scots pine, Norway spruce and Sitka spruce, indicating that the bending strength of larch is 13 to 17 MPa higher than that of spruce or pine when the knot area ratio and annual ring width are similar. The models for $E_{c,0}$ and $f_{c,0}$ cover Scots pine, Norway spruce and Sitka spruce. In compression, spruce is stronger than pine when density, knot area ratio and annual ring width are similar (see Figure 4).

Linear regression analysis was performed in general such that the regression equation was of the form

$$y = c + \sum c_i x_i$$

where y is the dependent variable, x_i are the independent variables, c is the constant of the model and c_i are the multipliers of the independent variables. In some cases it was observed that taking a logarithm of the dependent variable improved the model. Accordingly, a second type of regression equation studied was

$$\log_{10} y = c + \sum c_i x_i$$

The effect of diameter was also analyzed in bending and compression. The mechanical properties are adjusted to 12 % moisture content in accordance with the EN 384 standard. For E_m a clear positive trend was observed, i.e. the values increase with the increasing diameter of round timber. For other mechanical properties, no positive or negative size effect was observed, even when other physical properties were also taken into account. The results of Douglas fir, not included in the statistical analysis, clearly show that bending strength and stiffness increases with increasing diameter from 80 to 130 mm. The effect of diameter could not be observed for other species, because the effects of growth rate and diameter are interrelated. Therefore, the effect of age was studied separately. The analysis of the the Finnish material shows that a higher age gives higher characteristic compression strength. Detailed results of the statistical analysis are being published (Boren 2000, Boren and Barnard 1999).

Table 5. Multipliers for regression models including different species.

Variable	f_m	lg E_m	lg $f_{c,0}$	$E_{c,0}$
Constant	99.2	1.168	1.56	-0.606
KAR	-0.327	-0.00222	-0.002107	-0.0543
lg r	-30.5	-0.104	-0.169	-4.077
pine	-17.3	-0.0276		
spruce	-12.9			
spruce* ρ_{12}			0.0000654	0.00428
ρ_{12}			0.0005936	0.02788
u	-0.63		-0.02	
R^2	0.60	0.13	0.78	0.59

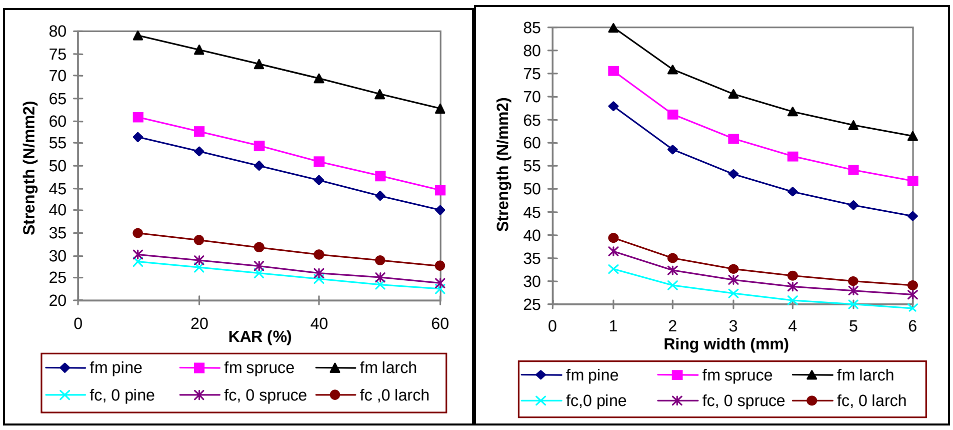

Figure 4. Illustration of the effect of KAR and ring width on the bending and compression strength of species when u = 12 %, p_{12}= 400 kg/m^3 for pine and spruce and 500 kg/m^3 larch, r = 2 mm for larch and 3 mm for pine and spruce or KAR = 10 % for larch and spruce, and 20 % for pine.

Comparison to sawn timber

Finnish spruce roundwood is compared to sawn timber (Norway spruce 42x145) as tested in a Nordic Industry funded project. Sample size is about 600 covering all Finland. For testing and analysis, EN 338, EN 384, EN 408 and EN 518 were applied. Cumulative distributions of bending strength, modulus of elasticity and density are given in Fig. 5. The 5th percentile value of bending strength of round spruce is double the value of sawn spruce even though the density distribution is fairly similar. The modulus of elasticity appears to be closely related to density, as expected. Please observe that a sample of 50 spruce specimens with low density are excluded in this comparison in order to obtain a similar density distribution both for sawn and round timber. For pine, similar information are given even though the sawn timber sample is less representative, and density of round timber is considerably lower. Also round pine does not include all specimens reported earlier in this paper.

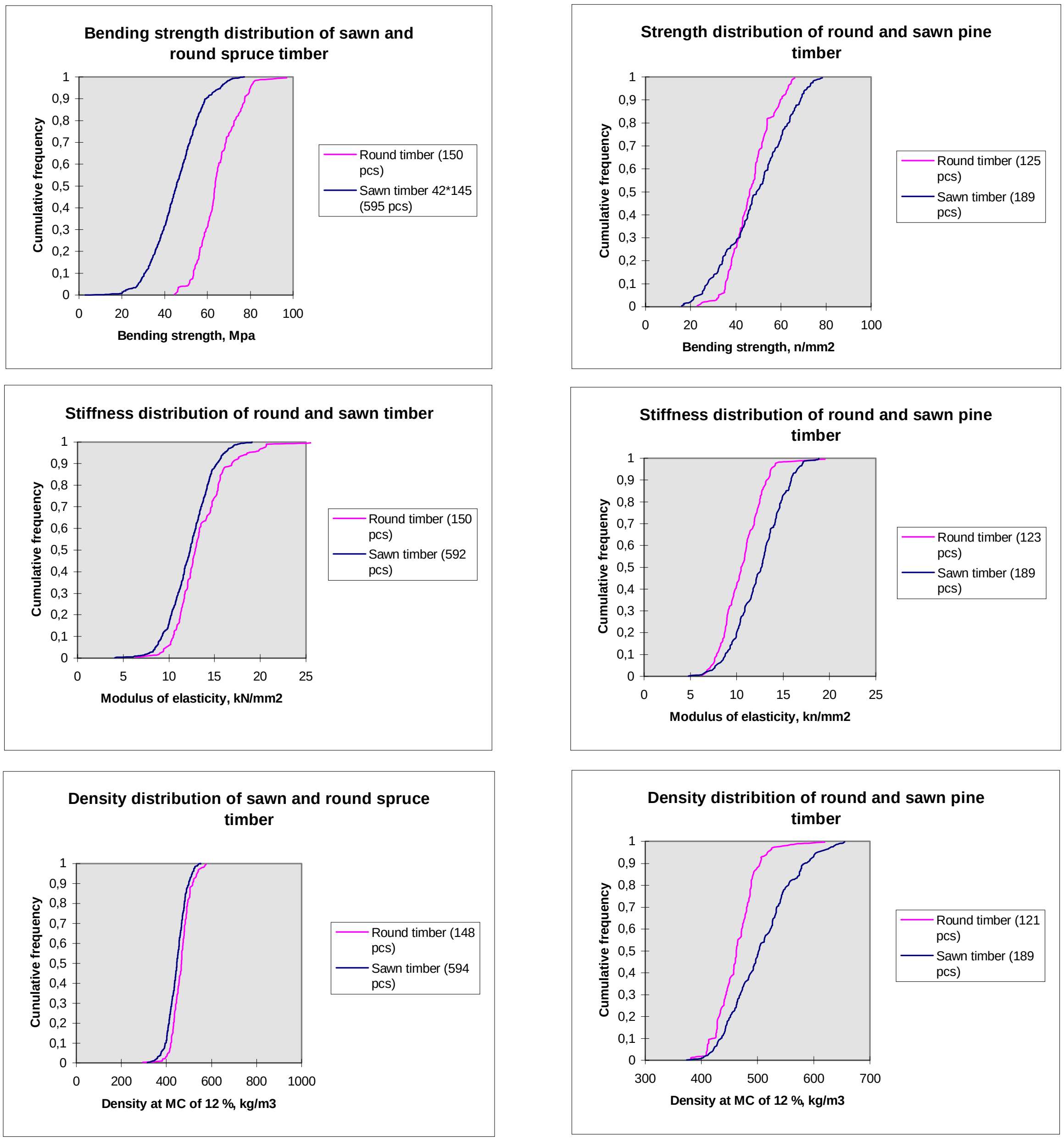

Figure 2. Comparison of bending strength, stiffness and density of round and sawn Finnish unsorted spruce and pine timber.

POSSIBLE STRENGTH CLASSES AND GRADING

Based on the statistical analysis of strength data a selection of visual strength-grading parameters was made, and preliminary limits for these parameters were set. A synopsis of the grading criteria for pine and spruce is given in Table 6. By applying the grading criteria to the tested samples the characteristic values were obtained as shown in Table 7, where the correspondence to the European strengh classes is also indicated. The procedure used to calculate characteristic values is in accordance with the upcoming European system except that we have considered also the compression strength results when determining strength classes. More details can be found in the final report (Ranta-Maunus 1999).

Table 6. Preliminary values for main strength-grading criteria of round Scots pine and Norway spruce.

Strength-grading criteria		Grade A	Grade B
Knot sum per diameter	ks/d [%]	75	100
Max. knot per diameter	mk/d [%]	25	30
Ring width	r [mm]	3	5

Table 7. Characteristic values of graded populations and location according to strength classes.

Species country	Grade	k_s	$f_{m,k}$ [N/mm^2]	$f_{c,k}$ [N/mm^2]	$E_{m,mean}$ [kN/mm^2]	ρ_k [kg/m^3]	Strength class
Norway spruce (FIN)	A	0.91	43.6	25.1	13.3	384	C30
Scots pine (FIN, UK)	A	0.84	33.9	23.1	14.0	450	C30
Scots pine (FIN)	B	0.86	30.2	18.7	11.8	411	C18

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