Small-Diameter Scots Pine and Birch Timber as Raw Materials for Engineered Wood Products

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ABSTRACT

In the future, the building industries will need predictable, homogeneous and cost-competitive wood products with structural safety in increasing quantity and quality. This can be provided by, e.g., breaking solid wood and reconstructing the structure in a way that the degrading influence of knots, cracks, decay and other natural irregularities in wood will be eliminated. Beams, panels or boards made by this principle are called the *engineered wood products* (EWP). The purpose of this study was to investigate the possibilities to utilize small-diameter Scots pine and birch timber for production of EWPs that are reconstituted of strands. The wood technological characteristics of the tree species used in these products worldwide were studied based on the literature, and the findings were compared to the characteristics of domestic woods. In addition, test specimens were manufactured from domestic raw materials of Scots pine and birch species, and tested in order to examine the differences between woods from young trees from the first commercial thinnings and top sections of mature trees from final cuttings as a raw material. According to the literature review, the average basic density and, consequently, many mechanical properties of pine and birch grown in Finland do not markedly differ from those of the numerous foreign species used for EWPs. The empirical tests indicated that beams (air-dry density ca. 620-800 kgm^{-3}) with relatively auspicious static stiffness (ca. 6000-8500 MPa) and bending strength (ca. 32-42 MPa) could be manufactured from timber equal to or smaller than pulpwood in diameter.

Keywords: *Betula sp., building, construction, density, EWP, Pinus sylvestris, small-diameter timber, stiffness, strength, Finland.*

INTRODUCTION

In Finland most of the small-diameter timber is used by the pulp and paper industries. There is also a governmentally subsidized objective to increase the use of wood for energy production. In addition, some small-diameter timber is used for sawing, in which case the raw material is referred to as small-sized logs. Their minimum top diameter ranges typically from 9 to 14 centimeters and length from 2.6 to 4.6 meters. Small-sized logs are obtained both from thinnings and from the top sections of larger trees. Softwood lumber from small-sized logs is targeted, in the first hand, for furniture manufacturing, glued laminated beams and boards, DIY-products, as well as house-yard building such as fences, decks, gazebos, sheds etc. (see: [34, 29, 36]). However, a great proportion of this lumber ends up to construction and packaging purposes due to its specific features in wood quality. Lumber obtained from small-diameter birch logs, on the other hand, is predominantly used in furniture and floorings [14, 19].

Due to the pronounced influence of stem form defects in the sawing process, the volumetric consumption of small-sized logs is high per unit volume of lumber in comparison to that of conventional logs, ca. 2.6 to 3.4 vs. 2.1 to 2.3 m^3 of logs per one m^3 of square-sawn lumber (e.g., [11, 37]). The sawn wood obtained from small-sized logs is predominantly sound-knotted, whereas the proportions of knot-free and dead-knotted sawn wood are smaller than in conventional logs (Scots pine, see: [11, 5, 17, 37]; birch, see: [14, 19]).

The conventional softwood lumber has some negative features from the viewpoint of the construction industries. On the one hand, the percentage of reject at building sites is considerable; only ca. 70-80% of the lumber delivered to the site ends up to the ready-made house. On the other hand, lumber always contains different kinds of defects that decrease the stiffness and strength and, therefore, increase the computational safety factors. These defects include, e.g., knots, cracks, decay, reaction wood, divergent grain orientation and wane. Therefore, the

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strength-weight ratio or the strength-dimension ratio of lumber is relatively poor in comparison to the competing materials such as steel and concrete.

Engineered wood products (EWP) consist of wood veneers, strands, flakes, chips or fibers bonded together by an adhesive. The reason for manufacturing EWP's is to obtain more predictable and homogenous wooden structures by chopping and evenly distributing the natural defects of wood throughout the product. This enables lighter and more graceful structures, longer spans and smaller safety factors in design values. Thus, the same volume of raw material provides more stiffness and strength in EWP's compared to the solid wood structures. In general, EWP's are partly competing against and partly complementary for traditional solid wood, metal or concrete-made construction materials. Most of the currently produced EWP's are either made of large logs, e.g., plywood, laminated veneer lumber (LVL), glued laminated beams, or their processing residues, e.g., medium density fiberboard (MDF) and particleboards. Still, some EWP's can be made of small-diameter timber or even wood waste (e.g., [20, 28]). These include at least oriented strand board (OSB), oriented strand lumber (OSL) and laminated strand lumber (LSL).

The purpose of this study was to determine the technical suitability of small-diameter Scots pine (*Pinus sylvestris*) and birch (*Betula pendula*, *B. pubescens*) timbers for selected EWP's on the behalf of their wood properties. Both timbers obtained from the first-thinning stands and the top sections of mature trees were studied.

MATERIALS AND METHODS

Tree species currently used in manufacturing OSB and LSL were mapped, and the values of their average basic density (kgm^{-3}) were searched from the literature and compared with those of small-sized timber of Scots pine and birch. Results on the density of small-sized Scots pine and birch wood in Finland have been published by [16, 31, 12, 13, 33].

In addition to the literature survey, empirical tests were made in collaboration of the Finnish Forest Research Institute and the Kymenlaakso Polytechnic, Laboratory of Wood Technology. Here, strand-made specimens from different wood raw materials were manufactured and tested in static bending, water absorption tests and dimensional swelling tests. The raw material strata studied were:

1. Scots pine bolts from the first commercial thinning, minimum top diameter 50 mm,
2. Scots pine bolts from the top sections of mature trees, minimum top diameter 50 mm,
3. Knot-free sapwood of large Scots pine butt logs (reference group),
4. Birch bolts from the first commercial thinning, minimum top diameter 50 mm,
5. Birch bolts from the top sections of mature trees, minimum top diameter 50 mm.

Samples of timber were gained for the empirical tests from South-eastern Finland. Table 1 presents the key characteristics of the thinning stands. The pine stand was a monoculture, whereas the birch trees originated from a mixed stand of Norway spruce (*Picea abies*) and birch. The sample trees represented the real commercial thinning removal, and were felled according to the principle of selective thinning from below. The mature Scots pine trees were cut from a dry heath. Both large butt logs and small-diameter top sections were obtained from the same trees. The small-diameter birch top sections originated from mature trees grown on a fresh heath. The age of the mature pine and birch trees were ca. 90 and 80 years, respectively.

In total, the volume of each raw material lot was ca. 0.2 m^3, except for Scots pine thinning wood (stratum 1), which comprised 0.5 m^3 (two strand thicknesses used in the tests on that stratum). The knot-free sapwood of pine (stratum 3) was obtained from two butt logs by sawing them in a way resulting to all heartwood remaining in the cant that was excluded from the test material. The small-diameter bolts as well as the sapwood slabs were debarked manually approximately one week after felling the trees. Debarking was finished using a pressure cleaner. Thus, unnecessary deviations in the test results caused by bark were avoided. Sample discs were crosscut from all bolts for determining their moisture content and basic density.

After debarking, the different raw materials were separately stranded using a Wigo laboratory-scale stranding machine. The nominal strand dimensions were similar to those used for oriented strand board, length ca. 100 mm, width 10-30 mm (all strata), and thickness 1.0 mm (strata 1-5) or 0.5 mm (stratum 1). The strands originating from different wood materials were kept separate during all phases of the process. The strands were dried in a laboratory oven to achieve the target moisture content of three per cent, and lightly screened in order to reduce the fines content of the strand material. Ca. 10% from the original strand mass was screened off as fines. The strand dimensions were measured from a random sample of 30 strands per stratum. The slenderness ratio, i.e., the ratio between the strand length and thickness, was calculated for each stratum separately.

Table 1. Mean characteristics of the thinning stands.

	Scots pine	Birch	
	Site class		
	Dryish heath	Vaccinium-myrtillus transformed drained peatland	
	Scots pine	Birch	Norway spruce
Basal area, m^{2}ha^{-1}	21	13	14
Dbh, cm	16	13	12
Heigth, m	13	16	11
Age, a	40	35	30

The strands were placed in a gluing drum and phenol-formaldehyde resin Exter 4566 was sprayed on them. This particular adhesive is usually used in gluing LVL-veneers, but after some preliminary tests, it turned out to perform relatively well also for strand-made specimens. The composition of the glue was as follows:

Phenol-formaldehyde (dry-matter content 47%)	100 weight units
K_2CO_3-hardener (dry-matter content 25%)	4 weight units

Similar amounts of glue were applied for all strata, 8% of dry glue (g) per dry wood (g). After gluing, the glue-covered strands were placed in a 1000 x 500 mm mold made of particleboard, with an underlayment of an aluminum plate. A plastic tube was used in orienting the strands during the scattering. Before the actual pressing, the mold was removed. The pressing temperature and time were 150°C and 13 minutes, respectively, the pressing schedule being presented in Table 2. The press used was a hydraulic water-heated Becker van Hüllen –press originally designed for pressing plywood.

Table 2. The pressing schedule for the targeted density classes as a function of time.

Press stage, min	Targeted density	
	600 kgm^{-3}	760 kgm^{-3}
	Pressure, MPa	
0.00 - 5.00	3.1	3.8
5.00 - 9.00	1.9	2.5
9.00 - 12.00	0.8	1.3
12.00 - 12.30	0.4	0.4
12.30 - 13.00	0.0	0.0

Four boards were manufactured from each raw material stratum, including two strand-thicknesses in stratum 1, thus totaling 24 boards. Two different target densities were specified for the boards, 600 kgm^{-3} for the small-diameter pine (strata 1 and 2) and 760 kgm^{-3} for the other strata (birch raw materials and pine sapwood). These were derived from the average densities of solid wood material measured from the sample discs. After pressing, the 25-mm-thick boards were edge-cut into dimensions of 900 x 450 mm using a circular saw, and placed for conditioning according to the conventional test standard (T = 20°C, RH = 65%). After conditioning, the boards were sawn into the dimensions of test specimens as follows:

- Static bending test edgewise, 900 x 50 mm, four specimens / board, total 16 specimens
- Static bending test flatwise, 500 x 50 mm, four specimens / board, total 16 specimens
- Swelling test, 50 x 50 mm, five specimens / board, total 20 specimens

The air-dry density ñ$_{12}$ (kgm^{-3}) as well as the modulus of elasticity MOE (MPa) and the modulus of rupture MOR (MPa) in four-point bending were measured from all bending test specimens. In addition, the moisture content MC was measured from one conditioned bending test specimen per board. The air-dry densities were determined for each specimen on the basis of the dimensions and mass. Finally, the swelling test specimens were sank in water for 24 hours, after which their dimensions and mass were measured again. The water absorptions, as well as the dimensional swelling characteristics were calculated on the basis of the two measurements.

The static bending tests were made in accordance with the standard EN 408 [9]. The results were studied both graphically and by linear regression. The following pre-assumptions were set on the results:

1. The density, swelling and bending properties of the specimens manufactured of small-diameter Scots pine or birch thinning wood do not differ from those of the specimens made of top sections of mature trees of respective species.
2. The specimens made of knot-free sapwood of Scots pine have better properties than the specimens made of small-diameter timber.
3. The thinner strands provide better stiffness, strength and swelling properties for the specimens than thicker strands.

The test hypotheses were formulated in accordance with the pre-assumptions and tested using Mann-Whitney U-test, H_0 being: no statistical difference occurs between the populations of the groups in comparison.

RESULTS AND DISCUSSION

Wood Density Survey

Ca. 30 tree species are used in the production of LSL, OSB and PSL worldwide (Table 3). OSB, being the most important of the strand-made EWP's, covers most of these species. In North America, OSB is predominantly made of aspens and poplars, southern pines, spruces, paper birch, red maple, sweetgum and tulip tree. However, these species are rarely used alone, usually a proper mixture of species is blended in order to get the wanted properties or price to the product. From the viewpoint of wood density, the only clearly distinctive species used in OSB are the eucalypts that are relatively dense in comparison to the other species used. In Europe, both Scots pine and Maritime pine are used in OSB. For poplars, Peters et al. [26] studied the properties of their hybrids (*Populus trichocarpa x P. deltoides, P. trichocarpa x P. nigra, P. trichocarpa x P. maximoviczii*) as raw materials for OSB. The mechanical performance of boards made of hybrid poplar was poorer than that of boards made of native aspen.

The comparisons of the average basic density between the species used in the production of OSB and LSL, and the Finnish small-diameter pine and birch showed no considerable differences, excluding eucalypt species. According to this evaluation, no hindrances occur for production of EWP's similar to OSB or LSL from Scots pine or birch. However, there are other properties that may influence the suitability of these species for EWP's. These include e.g., the mechanical performance and properties related with gluing, such as surface characteristics and permeability.

Laboratory Tests

The strand dimensions deviated to some extent from the targeted, being, on average, 0.52 mm and 0.8 mm in the target thickness classes of 0.5 and 1.0 mm, respectively. The largest dimensional deviations were in strands made of thinning birch, whereas the largest proportion of deformed strands was found in strands made of birch top sections. This may be due to the large sound knots in the top sections of birch trees, which impeded their stranding. The average strand dimensions as well as the slenderness ratios are presented in Table 4. Post [27] and Suchsland [30] reported that the bending strength of a strand-made product increases along with the average slenderness (length/thickness) ratio of the strands. Wang & Lam [38], who studied flakeboards made of 5-10-cm-long strands, found an asymptotic relationship between the slenderness ratio and bending strength, so that the highest strength was obtained with the slenderness ratio value of 133. In this study the average slenderness ratio of the strands was exactly the same in the reference group (stratum 3). Since the strand dimensions were measured from a relatively small sample of 30 strands per stratum instead of specimen-specific measurements, the relationship between the slenderness ratio and bending properties could not be determined more comprehensively.

The MC of conditioned boards varied between 11.3 and 11.9 per cent. Table 5 presents the results on air-dry density ($ñ_{12}$), water absorption and swelling. Density of an individual specimen varied relatively much along with the lateral and longitudinal location in the board. However, no systematics was observed in this variation. The within-stratum difference in the air-dry density varied from 125 kgm^{-3} to as high as 275 kgm^{-3}. Obviously, the manual strand alignment did not provide as homogeneous boards as expected. On average, the board densities were, however, relatively close to the targeted densities of 600 kgm^{-3} and 760 kgm^{-3}.

The average water absorption of the specimens was ca. 20 percentage units smaller in strata 3, 4 and 5 in comparison to strata 1 and 2. In addition, the water absorption decreased along with the increasing air-dry density. There were no differences of practical relevance between the separate strata. Therefore, only the results of stratum 4 are illustrated in Figure 1 as an example.

Linville [21] observed that the thickness swelling of strand-made boards increased in relation to the increment of board density. This was observed in this study as well, whereas the longitudinal and width swellings were not influenced by changes in the specimen density (Figure 2). Again, no significant differences were observed between the strata, and therefore only the results of stratum 4 are presented here.

A summary of the bending test results is presented in Table 6. The dependence of the MOE and MOR on the air-dry density of the specimen was studied using linear regression (Figures 3-6). Both MOE and MOR increased systematically along with the air-dry density, irrespectively of the stratum. However, the correlation coefficient between the air-dry density and MOE of specimens made of birch strands was distinctively low (Figure 5). Within the density class of 760 kgm^{-3} the best stiffness and strength values were observed for pine sapwood.

Table 3. Averages of the basic density for tree species used in the production of OSB, LSL and PSL worldwide [32, 35, 22, 25, 10, 15]. For the Finnish species we refer to [12].

Product	Species, English name	Species, Latin name	Region	Basic density of wood, kgm^{-3}
OSB	Paper birch	*Betula papyrifera*	USA, Canada	480
	Red maple	*Acer rubrum*	USA, Canada	490
	Sweetgum	*Liquidambar styraciflua*	USA	460
	Yellow-poplar, tulip tree	*Liriodendron tulipifera*	USA	400
	Balsam poplar	*Populus balsamifera*	USA, Canada	370
	Rubberwood	*Hevea brasiliensis*	Aasia, Australia	420
	American arborvitae, Northern white cedar	*Thuja occidentalis*	USA, Canada	350
	Aspen	*Populus spp.*		
	Quaking	*P. tremuloides*	USA, Canada	360
	Bigtooth	*P. grandidendata*	USA, Canada	390
	Eucalyptus	*Eucalyptus spp.*	Asia, Australia	
	Jarrah	*E. marginata*	Asia, Australia	670
	Karri	*E. diversicolor F.Muell.*	Asia, Australia	820
	Red alder, Oregon alder	*Alnus rubra, A. oregona*	USA	370
	Pine	*Pinus spp.*	All continents	
	Jack pine	*Pinus banksiana*	USA, Canada	420
	Maritime pine, Cluster pine	*Pinus pinaster*	Europe	430
	Radiata pine	*Pinus radiata*	Chile	400
	Scots pine	*Pinus sylvestris*	Europe	420
	Red pine	*Pinus resinosa*	USA	410
	Eastern white pine	*Pinus strobes*	Canada	370
	Southern (yellow) pine	*Pinus spp.*	USA	
	Loblolly	*P. taeda*	USA	470
	Longleaf	*P. palustris*	USA	540
	Shortleaf	*P. echinata*	USA	470
	Slash	*P. elliottii*	USA	540
	Spruce	*Picea spp.*	USA, Canada	
	Black	*P. mariana*	Canada	410
	Engelmann	*P. engelmannii*	USA, Canada	380
	Red	*P. rubens*	USA, Canada	380
	Sitka	*P. sitchensis*	USA, Canada	350
	White	*P. glauca*	USA, Canada	350
LSL	Aspen	*Populus spp.*		
	Quaking	*P. tremuloides*	USA, Canada	360
	Bigtooth	*P. grandidendata*	USA, Canada	390
	Yellow-poplar, tulip tree	*Liriodendron tulipifera*	USA	400
	Finnish species (grown in southern Finland)			
	Scots pine	*Pinus sylvestris*		
	Dbh > 15 cm			408
	Dbh 5-15 cm			404
	Birch	*Betula pendula, B. pubescens*		
	Dbh > 15 cm			485
	Dbh 5-15 cm			481

Table 4. Means (and standard deviations) of the strand dimensions and the slenderness ratio, i.e., the ratio between strand length and thickness, measured from a random sample of 30 strands per stratum.

Stratum	Thickness	Width	Length	Slenderness ratio
		mm		
1. Pine bolts from thinning				
a. Nominal strand thickness 0.5 mm	0.61 (0.19)	8.6 (6.0)	84.9 (21.2)	154 (63)
b. Nominal strand thickness 1.0 mm	0.82 (0.23)	14.3 (9.9)	78.4 (26.7)	103 (43)
2. Pine bolts from tops of mature trees	0.78 (0.23)	12.8 (8.5)	82.7 (21.6)	114 (42)
3. Sapwood of large pine logs	0.78 (0.29)	14.4 (14.4)	92.6 (17.3)	133 (52)
4. Birch bolts from thinning	0.77 (0.77)	17.6 (12.7)	83.9 (24.7)	113 (39)
5. Birch bolts from tops of mature trees	0.76 (0.21)	7.3 (4.1)	66.6 (24.5)	96 (51)

Table 5. Means (and standard deviations) of air-dry density ñ$_{12}$, water absorption (from 12% MC to wet) and thickness (T), width (W) and longitudinal (L) swellings measured from a sample of 20 test specimens per stratum.

Stratum	ρ_{12} kgm^{-3}	Water absorption %	Swelling %		
			T	W	L
1. Pine bolts from thinning					
a. Nominal strand thickness 0.5 mm	640 (45)	73.9 (7.1)	17.3 (2.9)	1.0 (0.3)	0.2 (0.2)
b. Nominal strand thickness 1.0 mm	626 (36)	72.2 (6.1)	15.8 (2.8)	1.3 (0.2)	0.3 (0.2)
2. Pine bolts from tops of mature trees	635 (48)	74.0 (5.9)	20.2 (4.0)	1.2 (0.2)	0.3 (0.2)
3. Sapwood of large pine logs	771 (62)	52.3 (5.0)	18.2 (3.4)	1.6 (0.3)	0.1 (0.2)
4. Birch bolts from thinning	789 (75)	54.0 (6.8)	22.0 (3.8)	2.1 (0.6)	0.4 (0.2)
5. Birch bolts from tops of mature trees	763 (44)	57.7 (5.1)	21.9 (3.3)	1.8 (0.5)	0.4 (0.2)

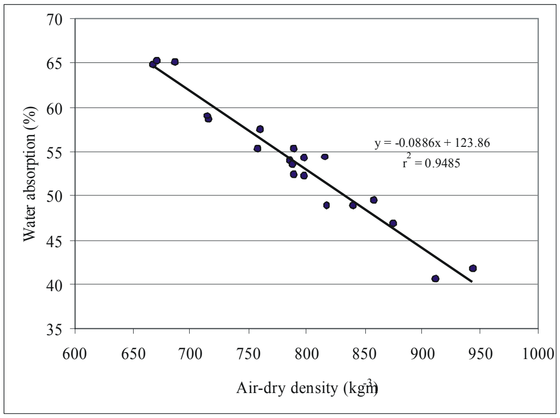

Figure 1. The relationship between water absorption and air-dry density in specimens made of thinning birch.

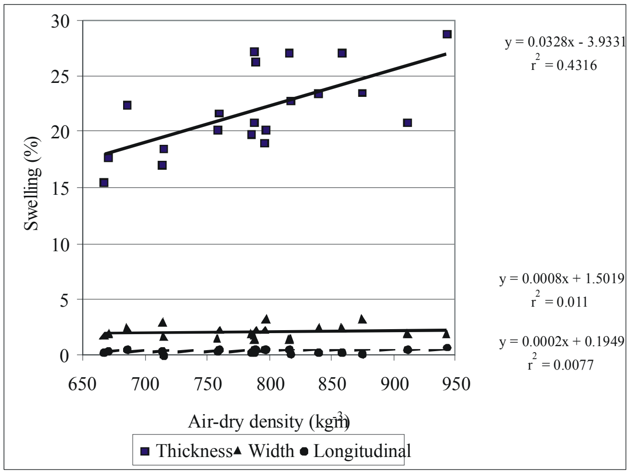

Figure 2. The relationship between dimensional swelling characteristics and air-dry density of specimens made of thinning birch.

This observation supported the hypothesis of the knot-free sapwood being the closest to an ideal raw material for this kind of product. On the other hand, also the strand dimensions, including the slenderness ratio, in stratum 3 were the most favorable for good bending test results (see: Table 4). Within the density class of 600 kgm^{-3}, the specimens made of pine thinning wood with nominal strand thickness of 1.0 mm had the lowest stiffness and strength values, the differences, however, being small. Generally, the between-stratum differences in both MOR and MOE were clearly more obvious within the density class of 760 kgm^{-3} in comparison to the density class of 600 kgm^{-3}. This observation was predominantly caused by the superior test results obtained in the reference group, stratum 3, whereas the between-stratum differences of the specimens made of small-diameter raw materials were not as evident.

According to the Mann-Whitney U-tests, the between-stratum differences in MOR and MOE were mainly significant (Table 7). In the case of the air-dry density, on the other hand, the between-stratum differences within the density classes of 600 kgm^{-3} and 760 kgm^{-3} were insignificant. There were no significant differences in the bending properties between the specimens made of pine thinning wood and top sections of mature pine trees. Furthermore, the strand thickness did not markedly influence the bending properties of pine thinning wood.

In the case of the birch-made specimens, all bending test results obtained using thinning wood were slightly higher than those obtained using top sections of mature trees. This may be due to the large sound knots that complicated the stranding process of the top bolts.

Table 6. Summary of the results from the static bending tests on the 25 mm x 50 mm specimens. Number of the specimens was either 15 or 16 in all strata.

Stratum		Static bending					
		Edgewise			Flatwise		
		ρ_{12} kgm^{-3}	MOE MPa	MOR MPa	ρ_{12} kgm^{-3}	MOE MPa	MOR MPa
1. Pine bolts from thinning							
a. Nominal strand thickness 0.5 mm	$\bar{x}$	655	6654	35.5	632	6646	44.7
	s	47	534	5.6	34	541	5.1
	Min	585	5619	23.4	564	5356	32.9
	Max	742	7459	45.3	702	7416	50.5
b. Nominal strand thickness 1.0 mm	$\bar{x}$	624	5819	31.6	631	6649	40.2
	s	27	444	2.9	28	548	5.4
	Min	573	4904	25.2	582	5443	29.8
	Max	672	6556	37.9	682	7641	49.3
2. Pine bolts from tops of mature trees	$\bar{x}$	632	6415	32.0	628	6496	41.1
	s	29	383	2.8	29	498	4.8
	Min	565	5497	25.3	592	5670	33.3
	Max	679	7115	35.2	682	7291	50.9
3. Sapwood of large pine logs	$\bar{x}$	795	10121	48.8	771	9727	59.5
	s	48	766	7.9	43	970	11.5
	Min	711	8219	35.2	701	8161	38.1
	Max	912	11104	61.8	837	11351	76.4
4. Birch bolts from thinning	$\bar{x}$	788	8451	42.5	775	8637	51.8
	s	27	1056	8.0	38	969	8.1
	Min	742	5354	24.2	669	6185	29.1
	Max	826	9659	57.3	848	9729	62.2
5. Birch bolts from tops of mature trees	$\bar{x}$	795	7549	37.1	761	7087	43.4
	s	32	694	4.0	34	761	5.4
	Min	751	5868	28.7	673	5286	35.9
	Max	853	8507	44.0	830	8093	53.0

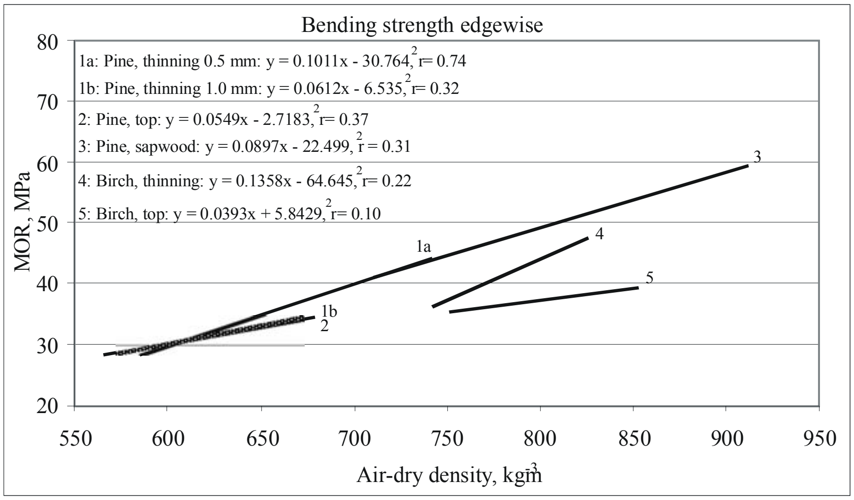

Figure 3. The dependence of MOR on the air-dry density of the specimen in edgewise static bending by stratum.

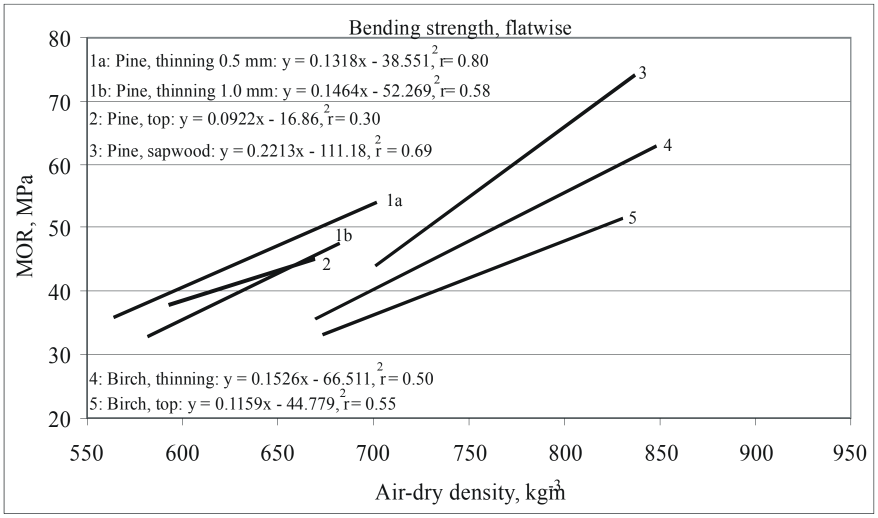

Figure 4. The dependence of MOR on the air-dry density of the specimen in flatwise static bending by stratum.

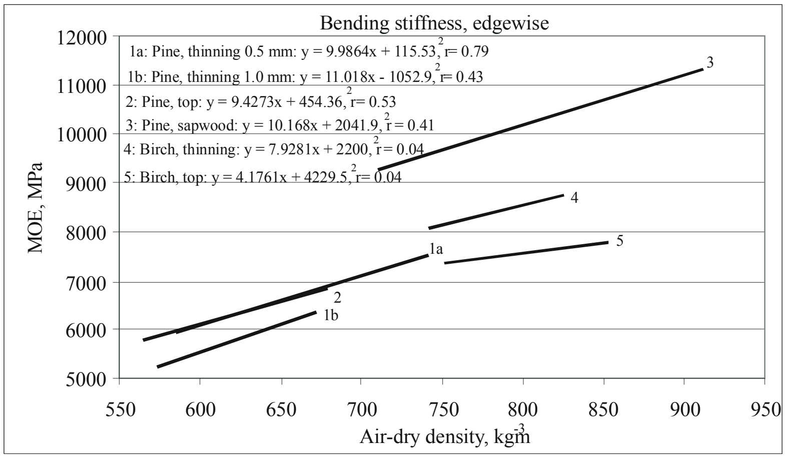

Figure 5. The dependence of MOE on the air-dry density of the specimen in edgewise static bending by stratum.

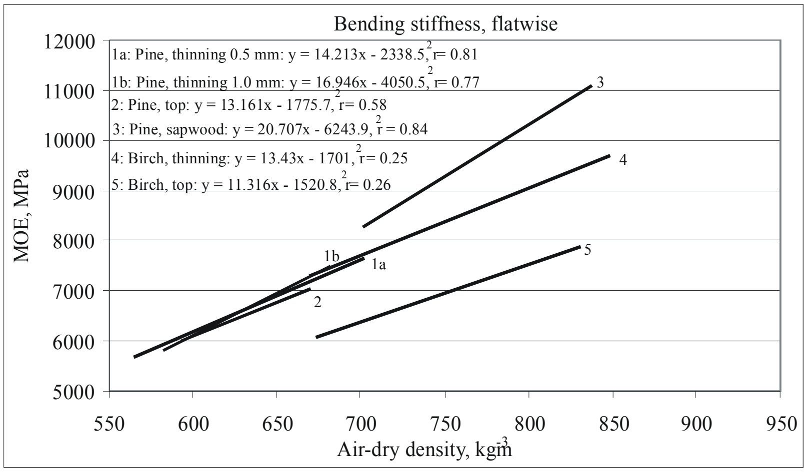

Figure 3. The dependence of MOE on the air-dry density of the specimen in flatwise static bending by stratum.

Table 7. The results of the pairwise Mann-Whitney U-tests on MOE, MOR and ñ$_{12}$ in edgewise and flatwise bending at 5% risk level.

Pair	Bending edgewise			Bending flatwise		
	MOE	MOR	ρ_{12}	MOE	MOR	ρ_{12}
	p-value					
Pine thinning wood, nominal strand thickness 0.5 mm vs. Pine thinning wood, nominal strand thickness 1.0 mm	0.000	0.010	0.080	0.780	0.014	0.897
Pine thinning wood, nominal strand thickness 1.0 mm vs. Top sections of mature pine trees	0.000	0.338	0.270	0.402	0.696	0.780
Birch thinning wood vs. Top sections of mature birch trees	0.001	0.015	0.564	0.000	0.000	0.056
Birch raw materials vs. Sapwood of pine butt logs	0.000	0.000	0.974	0.000	0.001	0.983
Raw materials representing density class 600 kgm^{-3} vs. Raw materials representing density class 760 kgm^{-3}	0.000	0.000	0.000	0.000	0.000	0.000

Since the mass of the adhesive in relation to the mass of the strands was equal in all strata, a smaller amount of adhesive was used per volume and area when gluing the 0.5-mm-thick strands than in the case of 1.0-mm-thick strands. In addition, the time needed for aligning the thinner strands was longer than that of thicker strands, which resulted in slightly too much dried glue before the actual pressing stage. These factors were suspected to influence negatively the bending test results. Still, the results were significantly better for the specimens made of thinner strands, the only exception being for stiffness in flatwise bending test. Due to the relatively small material available in this study, this finding requires more validation. However, similar observations were published earlier for particleboard [18, 27]. Even if the thinner strands seem to provide a better mechanical performance, decreasing thickness in production environment is restricted since thin strands tend to break easily [23].

The bending strength of strand-made beams increases systematically along the strand-length increment up to the length of ca. 15 cm [23]. Above that, the bending properties are not essentially dependent on the length and width of the strands. This finding is based on studies made with three different nominal strand lengths (10, 20 and 30 cm) and widths (1.25, 1.9 and 2.5 cm). In the case of more than 15-cm long raw material strands, the principal factors affecting the mechanical properties of the products are density [23, 6], strand-uniformity [3, 24] and the orientation of the strands [1, 2, 4, 23, 7, 8, 39, 40]. The strand length, on the other hand, mainly determines the success of the orientation.

CONCLUSIONS

The results of this study indicated that, from the wood technological point of view, there are no obvious reasons why small-diameter Scots pine or birch timber could not be used in strand-made EWP's in Finland. However, the material available for this study was inadequate for generalizations. Due to the considerable variations in the strand dimensions and the density of the specimen within and between the studied strata, the results of the bending tests showed large deviations. The first task in the further tests is to reduce this variation. On the other hand, the dimensional swelling characteristics did not differ markedly between the strata. It seems that products similar in the structure to the specimens prepared in this study would be comparable, and perhaps after some development work even superior to conventional structural lumber, in terms of stiffness and strength. Still, the thickness swelling, as typical to the strand-made products, is manifold higher than that of solid lumber.

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