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SOFTWOOD BARK FOR MODERN COMPOSITES

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Abstract:
The forestry and timber industry is facing a general lack of resources further compounded by harsh competition from biomass based energy. Therefore the development of alternative resources has become increasingly important. The present investigation focuses on the heretofore barely utilized potential of tree bark of softwoods. Bark is a byproduct of timber manufacturing in sawmills and exhibits very interesting properties. In this study insulation boards and pallets blocks, made out of pine and other softwood barks, have been produced. Their properties seem to be promising with regard to thermal conductivity, heat storage capacity and mechanical characteristics for the insulation boards but also in terms of internal bond after weathering, nailing and low formaldehyde emission for the pallets blocks. For this reason bark based panels could probably be used efficiently for civil engineering purposes like heat insulation and sound absorption, transportation like pallets blocks and other specific applications in general. The actuals results were patented and a continuation of the research with other softwoods like larch and hardwoods like oak will be carried out.

Key words: *softwood bark; insulation boards; pallets blocks.*

INTRODUCTION

An analysis of the logs market has shown that the production of wood products can only be enhanced if roundwood imports can be increased or unutilized wood reserves can be mobilized. With regard to the current mobilizing strategies and the resource availability in European Union both opportunities alone seem to be improbable (Barbu 2011).

The global logging harvest utilized for industrial purposes totals roughly 1.6 billion solid m³ and represents only 43% of total cuts as the majority is directly burned. In the European Union this amount is about 310 million solid m³ and it represents about 80% (Barbu 2011). Considering that the average bark content of a tree is approximately 10%, utilization of bark would result in approximately 160 million m³ of additional raw material in the world (Xing *et al*. 2007) and about 31 million m³ bark in EU (Barbu 2011).

A long tradition can be found in the use of bark as raw material in various wood based panels (for instance Volz 1973, Nemli *et al*. 2005, Xing *et al*. 2007, Kraft 2007, Yemele *et al*. 2008). All those studies show that increased bark content results in poorer mechanical board properties than conventional particleboard or fiberboard. A recent study carried out by Gupta *et al*. (2011), Kain *et al*. (2012) showed that bark panels with a density higher than 800kg/m³ can be produced without using additional resin.

Naundorf *et al*. (2004) produced bark pellets, suitable as a blow-in insulation material. Whereas the thermal properties of wood have been adequately studied (for example Suleiman *et al*. 1999), there are fewer studies focusing on the thermal characteristics of bark. Warnecke (2006) produced bark panels bound with natural adhesives with a relatively high thermal conductivity of 0.16W/(m*K). The thermal conductivity of bark was studied by Martin (1963) and it was found that it is approximately 30% lower than that of solid wood. The specific heat storage capacity was measured by Gupta *et al*. (2003) and the results showed that it is comparable to that of wood.

The target of this research was to produce bark based panels (both for insulation purposes and as pallet parts) and to clarify whether bark, especially pine bark (*Pinus sylvestris*) is suitable as a raw material for special purpose boards.

MATERIAL AND METHODS

Material for the investigation

The bark for the current study was collected in a small Upper Austrian softwood sawmill. According to the sawmill owner the wood species is 90% common pine (*Pinus silvestris*) and 5% of both spruce (*Picea abies*) and fir (*Abies alba*).

Sample taking was carried out following the method developed by Paper Wood Austria (2009) for industrial wood chips grading. Thereby bark chips were taken from the upper layer of the bark pile at several spots. Additionally the bark chips were withdrawn at an approximate depth of 30cm to avoid changing effects at the boundary layer. The bark was subsequently dried with a vacuum dryer from an initial moisture content of 100% to a final moisture content of 6%.

Manufacturing of one-layer insulation boards

Out of the bark material mentioned on the outset (90% pine, 5% spruce and fir respectively) boards were produced. First of all the coarse bark particles were milled in a 4-spindle-shredder. Within the machine a 30mm mesh sieve was installed to limit the dimensions of the over-sized particles after milling. The milled particles were fractionated continuously using hand sieves to obtain two bark fractions x_1 and x_2. Thereby the particle distribution was classified by following criteria: 30mm > x_1 ≥ 13mm, 13mm > x_2 ≥ 8mm. Dust, fines and particles smaller than 8mm were not used for the insulation board production. Afterwards the bark particles were resinated with an urea formaldehyde (UF) glue in a laboratory blender. To conclude the process bark based insulation panels (Fig. 1) with a thickness of 20mm and a target density of 350, 400 and 500kg/m³ were produced using a laboratory press (Fig. 2).

Fig. 1
Bark based insulation panel (thickness 20mm, density 400kg/m³, particle size 30mm > x_1 ≥ 13mm).

Manufacturing of pallet blocks

Using the same way to prepare the particles from bark chips many fractions (seven) were graded to reach an optimized bark particle geometry mixture. After grading the particles in several fractions like fines (x_1 < 15mm), medium (15mm < x_2 < 25mm), large (25mm < x_3 < 35mm) and coarse (x_4 < 45mm) were dried to a final m.c. of 5% in order to secure an appropriate adhesion and thus a long term dimensional stability of the pallet blocks.

For the specific use of the pallets the resins used for the blending of bark and wood particles (different mixture ratio: 100 to 25%) were UF and melamine reinforced UF (mUF) in different amounts. The same blender used for the insulation boards was in operation. The resin amount was higher than for particleboard faces (> 8%) but the same like for wood particle based pallets blocks (<15%). For the forming of the mat a special built steel box with the height of the pallets blocks (78mm) was used. This steel forming box equipped with a special closing system was used to achieve different target densities (600 to 750kg/m³). The lab hot press (Fig. 2) set at 200°C temperature of steel plattens and a pressing time of 8s/mm allowed to cure the resinated bark particles accurately.

Fig. 2
Lab hot press (80x80cm) and steel box (30x30cm) for forming 78mm blocks.

After hot pressing and pressure release the thick bark particle (mixed with wood) board was cut-to-size into six blocks of 100x145mm which were used for a variety of further normed trials (Fig. 3).

Fig. 3
Bark based pallets blocks panel (thickness 78mm, density 675kg/m³, particle size < 15mm).

Experimental design and data analysis

The factorial design used in this investigation of insulation boards is shown in Table 1. The factors chosen were density (350, 400 and 500kg/m³), resin content (0.08, 0.12) and bark particle size (30mm > x_1 ≥ 13mm, 13mm > x_2 ≥ 8mm). During panel production it was found that panels with a density of 400kg/m³, 8% resin content and particle size x5 showed insufficient strength properties due to lacking compression. Therefore no panels with the same density and particle size, but only higher resin content were produced. In

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return a test panel with a density of 350kg/m³ and coarser particles (x_4) with a UF resin content of 12% was pressed. This led to 8 combinations with three replicates (apart from the last panel) each. In total 22 panels were produced.

The statistical analysis software package SPSS 18 was used for the data processing. An analysis of variance was performed to evaluate the factor influence on the different dependent variables. As the dispersion of panel density is partly high, the panel density was included as a covariate in ANOVA.

Table 1

Experimental design with factors density, particle size and resin content (based on the oven dry weight of bark particles) for the bark based insulation boards

Density in kg/m³	Particle size in mm	UF resin content in kg/kg	No. of specimens
500	30 mm > x_1 ≥ 13 mm	0.12	3
		0.08	3
	13 mm > x_2 ≥ 8 mm	0.12	3
		0.08	3
400	30 mm > x_1 ≥ 13 mm	0.12	3
		0.08	3
	13 mm > x_2 ≥ 8 mm	0.12	-
		0.08	3
350	30 mm > x_1 ≥ 13 mm	0.12	1

The factorial design used in this investigation of pallet blocks is shown in Table 2. The factors chosen were density (600, 675 and 750kg/m³), resin type (UF and mUF) and content (0.08, 0.10 and 0.12) and particle size (x_1 < 15mm < x_2 < 25mm < x_3 < 35mm < x_4 < 45mm) During the first test series (density of 750kg/m³) it was found that blocks with a particle size of x_3 > 25mm showed insufficient strength properties due to inhomogeneous compression of the particles. Therefore no blocks with particle sizes > 25mm were produced. This led to 24 combinations with two replicates each. In total 48 different blocks were produced.

Testing the board properties

All **bark based insulation boards** were tested for their mechanical properties. The tests were conducted according to the procedure specified in the European standards EN 310, EN 319, EN 317 (1993), DIN 52192 (1979) and DIN 52188 (1979). After conditioning the panels at 20°C and 65% relative air humidity for one week, they were cut into samples (following EN 326-1 (1994), after what samples were taken from different positions within one board to randomize density differences due to the production process) to test static bending (modulus of elasticity - MOE and modulus of rupture - MOR), compressive resistance (CR), internal bond (IB), tensile strength (T), thickness swelling (TS) and water absorption (WA) after 2/24h immersion in water at 20 °C. All boards were also evaluated for their physical density.

For **wood particle based pallets blocks** the UIC-Codex 435-2 specifies the certification and use for EUR-pallets and consists of seven tests. The **bark based pallets blocks** samples were tested for density, m.c., boiling resistance, thickness swelling, internal bond, nails withdrawal and free formaldehyde emission. The critical test of these is the internal bond (IB) after two hours boiling and cooling in water which limited the initial research design.

Table 2

Experimental design with factors density, particle size and resin content (based on the oven dry weight of bark particles) for the bark based pallet blocks

Density in kg/m³	Particle size in mm	UF resin content in kg/kg	No. of specimens
750	$x_1 < 15$ mm	0.12	2
		0.10	2
		0.08	2
	$15 < x_2 < 25$ mm	0.12	2
		0.10	2
		0.08	2
	$25 < x_3 < 35$ mm	0.12	2
		0.10	2
		0.08	2
	$35 < x_4 < 45$ mm	0.12	2
		0.10	2
		0.08	2
675	$x_1 < 15$ mm	0.12	2
		0.10	2
		0.08	2
	$15 < x_2 < 25$ mm	0.12	2
		0.10	2
		0.08	2
600	$x_1 < 15$ mm	0.12	2
		0.10	2
		0.08	2
	$15 < x_2 < 25$ mm	0.12	2
		0.10	2
		0.08	2

Measuring the thermal conductivity

The thermal conductivity of the insulation boards was determined following the European standard EN 12667 (2001) with the thermal conductivity measurement device EP500 of Lambda-Measurement Technologies Corporation (Fig. 4).

The sample with given thickness is positioned between the two plates of different temperatures. When the temperature gradient during the sample is stationery, the heat flow through the sample is constant and the thermal conductivity can be calculated (Kain 2012).

The thermal conductivity of bark boards (500x500x20mm) was measured. The bark based insulation panels showed a moisture content (m.c.) of 12.2% on average with a standard deviation of 0.6%.

Fig. 4
Measuring device for thermal conductivity (Lambda-Meter EP500).

RESULTS

Physical and mechanical board properties

As known from literature mechanical board properties are strongly influenced by panel density (e.g. Yemele *et al*. 2008). This coherence could be also shown for the produced low density **bark based insulation panels**. In Table 3 one can see that panel density is highly significantly ($p < 0.001$) positively correlated with CR, MOR, MOE, T and IB. The correlation between panel density and thickness swell is significant ($p < 0.05$) and positive, while panel density didn't effect water absorption.

A 2-factorial ANOVA including the covariate density showed that additionally the resin content has a highly significant influence on all the mechanical board properties where the panel properties are clearly better when using 12% instead of 8% resin.

For IB, TS and WA also the particle size has a highly significant effect showing that for those properties finer particles have a negative effect.

Table 3

Coefficient of correlation (Pearson) between panel density and mechanical insulation board properties

	CR	MOR	MOE	T	IB	TS	WA
Coefficient of correlation	0.943	0.832	0.610	0.790	0.741	0.329	-0.167
Significance level	0.000	0.000	0.000	0.000	0.000	0.038	0.303
Sample size	40	40	39	74	39	40	40

For the **pallets blocks** is to notice that with regard to IB (twice than the UIC admissible value of 0.25N/mm²) and nails withdrawal the best results were achieved with samples made from the fine bark fraction (x_1< 15mm) compared to those made of longer or coarser particles (Fig. 5).

The same positive trends could be found by increasing the density, resin amount and melamine ratio of the resin. The bark in the pallets reduces the free formaldehyde amount by 45% compared to the samples made out of 100% wood particles, same resin type, amount and density. The emission value is between F4* and F5* or E1/2.

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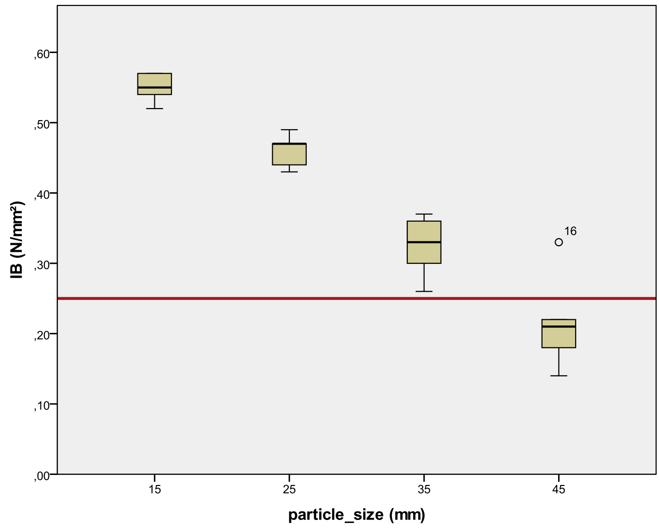


Fig. 5
IB of bark pallets blocks (thickness 78mm, density 675kg/m³, resin amount 10%) vs. particle size.

Thermal bark properties

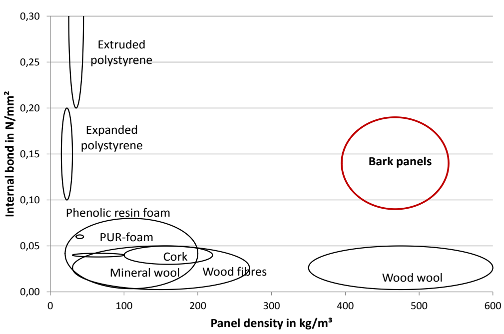
For the thermal conductivity measurements of the investigated bark samples the influence of the independent variables UF resin content (0.08, 0.12), particle size (30mm > x_1 ≥ 13mm and 13mm > x_2 ≥ 8mm) and the covariate density on the dependent variable thermal conductivity was tested using a two-factorial analysis of variance. The results showed that neither the resin content nor the particle size has a significant influence on the thermal conductivity of the bark samples. The sample density however has a highly significant ($p < 0.001$) influence on the thermal conductivity. The thermal conductivity accounts for 0.065W/(m*K) for boards with a density of 350kg/m³ and 0.08W/(m*K) with 550kg/m³.

Interpretation of the results

In order to evaluate the mechanical properties of bark based insulation panels, compressive resistance and internal bond (which are most important for insulation boards) were compared to those of commonly available insulation boards. Fig. 6 shows that internal bond won't be the restrictive material parameter, of course due to the relatively high density. Similarly the other tested mechanical board properties of the insulation boards are relatively high compared to other available insulation panels (Kain *et al*. 2012).

An analysis of the thermal properties shows that bark panels with the same density as spruce (*Picea abies*) (470kg/m³ and 15% m.c.) show with 0.084W/(m*K) an approximately 30% lower thermal conductivity than solid wood (Fig. 7), which is comparable to measurements taken by Martin (1963). The lighter boards (370kg/m³) showed a thermal conductivity of 0,065W/(m*K) which otherwise is for example reached with bloated perlite.

More important nevertheless is the fact that bark has a very low thermal diffusivity resulting in a very slow temperature shift in a buildings wall construction (Fig. 8).



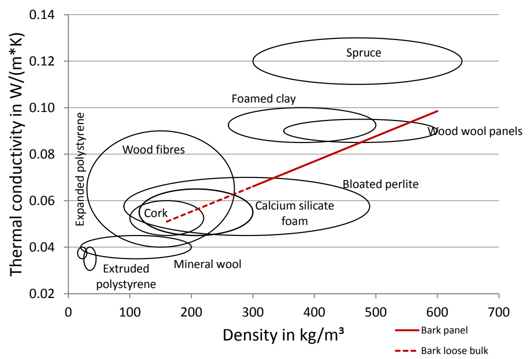


Fig. 6
Internal bond of bark based panels compared to commonly available insulation materials (data apart from bark according to Pfundstein et al. 2007, p. 13).
Fig. 7
Thermal behavior of bark based panels compared to other important insulation materials (data apart from bark according to Pfundstein et al. 2003, p. 9).

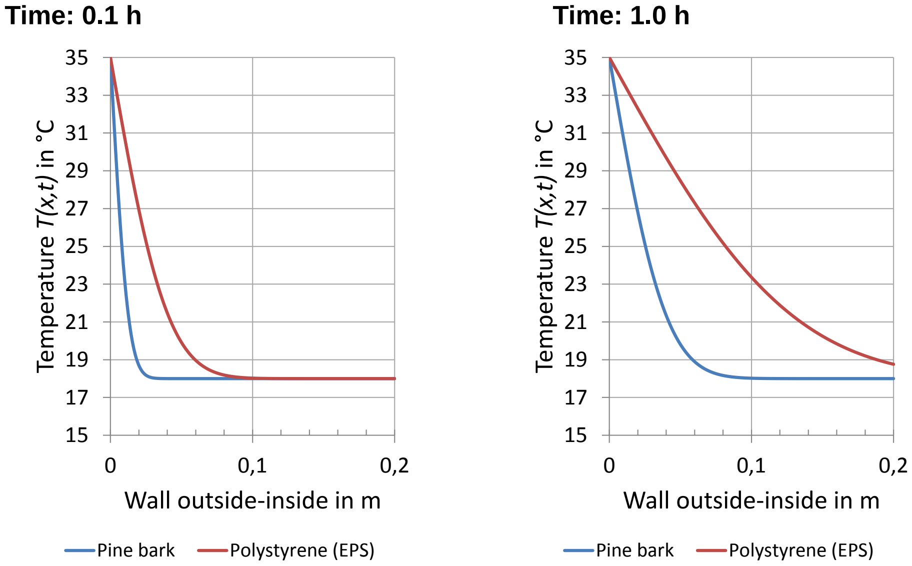


Fig. 8
Temperature profiles in a wall of different materials subjected to a temperature difference of 17 °C.

CONCLUSIONS

Bark is available in large quantities and is up to now not used a lot for products with a higher value added. As tree bark has interesting characteristics in order to protect a tree's inner life, one can assume that it also could be suitable as an insulation material and packaging products.

Within this study light weight bark based insulation panels and bark based pallets parts were produced. With regard to mechanical properties of the insulation panels their properties are more than sufficient. Also the thermal conductivity is sufficient for insulation applications.

The trials for the pallets blocks made from bark proved the tested values fit easily the requests of norms having important advantages in term of raw material costs and availability.

The bark could be still used for heating purposes or recycling in other industry after the lifetime of these innovative products.

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REFERENCES

Ashby MF (2011) Materials selection in mechanical design. (4th edition) Elsevier, Oxford. Pp. 646

Backhaus K, Erichson B, Plinke B, Weiber R (2011) Multivariate data analysis. (13th edition) Springer, Berlin, Heidelberg. Pp. 583 (in German)

Barbu MC, Pieper O (2008) Light fiberboards for insulation purposes. Proceeding of COST E49 Workshop on "Lightweight Wood based Composites": pp. 34-51

Barbu MC (2011) Current developments in the forestry and wood industry. PRO LIGNO 7(4):111-124

EN 12667 (2001) Determination of the thermal resistance with the panel and heat flow panel measuring device. (in German)

Fengel D, Wegener G (2003) Wood – chemistry, ultrastructure, reactions. Kessel Verlag, Remagen. Pp. 613

Gammerith H (1996) Insulation materials. Department for engineering and industrial building, Technical university, Graz. Pp. 13 (in German)

Gupta M, Yang J, Roy C (2003) Specific heat and thermal conductivity of softwood bark and softwood char particles. Fuel 82:919-927

Gupta G, Yan N, Feng MW (2011) Effects of pressing temperature and particle size on bark board properties made from beetle infested lodgepole pine (Pinus contorta) barks. Forest Products Journal 61(6):478-488

Heinzmann B (2012) Aufbauelement, insbesondere Palettenklotz, Palettenkufe oder Palettenkufenbrett für eine Transportpalette. Gebrauchsmuster Nr.202011004658.3, Deutschespatent und Markenamts.

Heinzmann B (2012) Research on value-add increase for bark by pressing pallets blocks. Masterthesis, University of Applied Sciences Salzburg, Department for Wood and Biogene Technologies (in German)

Heinzmann B, Barbu MC (2013) Untersuchungen zur Steigerung der Wertschöpfung von Rinde durch Verpressen zu Palettenklötzen. Holztechnologie no. 54(4):5-17

Kain G (2012) Substantial bark use as insulation material. Masterthesis, University of Applied Sciences Salzburg, Department for Wood and Biogene Technologies (in German)

Kain G, Teischinger A, Musso M, Barbu MC, Petutschnigg A (2012) Thermal insulation materials out of tree barks. Holztechnologie 53(4):31-37 (in German)

Kain G, Barbu MC, Heinzmann B, Petutschnigg A (2012) The use of bark for wood based panels. Proceeding of 11th Pacific RIM bio-based Composites Symposium (Biocomp), Shizuoka, pp. 66-74

Kraft R (2007) Chemical-technical utilization of used engineered wood products and tree bark. Dissertation, University Göttingen. Pp. 118 (in German)

Martin RE (1963) Thermal properties of bark. Forest Products Journal 18(11):54-60

Naundorf W, Wollenberg R, Schubert D (2004) Refinement of bark towards granular filler and insulation materials. Holz als Roh- und Werkstoff 62:397-404 (in German)

Nemli G, Colakoglu G (2005) Effects of Mimosa bark usage on some properties of particleboard. Turkish Journal of Agriculture and Forestry 29:227-230

Paper Wood Austria (2009) Timber acquisition guidelines. Version 7. (in German)

Pfundstein MR, Gellert M, Spitzner H, Rudolphi A (2007) Insulation materials – basics, materials, applications. Department for international architecture ducumentation corporation, Munich, pp. 112 (in German)

Suleiman BM, Larfeldt J, Leckner B, Gustavsson G (1999) Thermal conductivity and diffusivity of wood. Wood Science and Technology 33:465-473

Volz KR (1973) Manufacturing and properties of spruce, pine and beech bark panels. Wood Science and Technology 31:221-229. (in German)

Warnecke C (2006) Development of a process to produce insulation and construction materials out of spruce bark without synthetic resins. Dissertation, Technical University Freiberg. Pp. 194 (in German)

Xing C, Zhang SY, Deng S, Wang S (2007) Investigation of the effect of bark fiber as core material and its resin content on three-layer MDF performance by response surface methodology. Wood Science and Technology 41:585-595

Yemele MCN, Cloutier A, Diouf P N, Koubaa A, Blanchet P, Stefanovic T (2008) Physical and mechanical properties of particleboard made from extracted black spruce and trembling aspen bark. Forest Products Journal 58(10):38-46