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Effect of Pine (*Pinus Sylvestris*) Bark Dust on Particleboard Thickness Swelling and Internal Bond

Utjecaj dodatka prašine napravljene od borove kore na debljinsko bubrenje i čvrstoću raslojavanja ploča iverica

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ABSTRACT • *Increasing demand for wood resulted in competition between different branches of wood-based production. High intensity production, like the production of wood-based panels, is forced to look for other lignocellulosic resources. Bark is a possible source for wood-based panel industry, especially for particleboards. Bark chips were crushed into bark dust, which were used for the production of single-layer particleboards. The share of bark dust was 0 %, 0.5 %, 1 %, 5 % and 10 %. The boards were tested on thickness swelling (immersion in water, exposure to humid conditions) and internal bond. The highest internal bond was determined in the particleboard with 1 % bark share. Thickness swelling of boards with added bark was higher compared to boards without bark. The highest swelling was observed in boards with 10 % bark dust (immersion in water) or 5 % (humid conditions). Bark based boards absorbed less water.*

Keywords: *bark dust, particleboard, thickness swelling, water absorption, internal bond*

SAŽETAK • *Sve veća potražnja drva pojačala je konkurenciju među različitim granama proizvodnje na bazi drva. Proizvodnje velikog kapaciteta kao što je proizvodnja ploča na bazi drva prisiljene su tražiti i druge lignocelulozne resurse za svoju proizvodnju. Jedan od mogućih izvora za proizvodnju drvnih ploča, posebno ploča iverica, jest drvna kora. Za potrebe ovog istraživanja sječka proizvedena od kore usitnjena je u drvnu prašinu koja je iskorištena za proizvodnju jednoslojnih iverica. Udio usitnjene kore u pločama bio je 0; 0,5; 1; 5 i 10 %. Ispitano je debljinsko bubrenje proizvedenih ploča (nakon potapanja u vodi, nakon izlaganja vlažnim uvjetima) te čvrstoća raslojavanja. Najveća čvrstoća raslojavanja utvrđena je za ploču ivericu s 1 % udjela kore. Debljinsko bubrenje ploča s dodatkom kore bilo je veće od bubrenja ploča bez dodatka kore. Najveće debljinsko bubrenje zabilježeno je u ploča s 10 % usitnjene kore (nakon potapanja u vodi) ili s 5 % usitnjene kore (nakon izlaganja vlažnim uvjetima). Rezultati istraživanja pokazali su da ploče iverice proizvedene s dodatkom usitnjene kore upijaju manje vode.*

Ključne riječi: *usitnjena kora, iverica, debljinsko bubrenje, upijanje vode, čvrstoća raslojavanja*

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1 INTRODUCTION
1. UVOD

In the last decade(s), the production of wood-based panels has been constantly increasing (FAO, 2016), causing an increasing demand for wood and also resulting in competition between different companies that depended on wood supply (sawmill, construction, wood-based panels, energy production). Due to the increasing demand for wood, not only for wood-based panel production, but also for other purposes (sawmill, energy), wood-based panel industry is forced to look for other lignocellulosic resources. Bark is also a potential resource. Bark is one of the most common residues generated by the forest industry, the sawmilling industry or by the wood-based panel industry. Although bark is used for energy and landscaping, pharmacy, as tannin source, most of the bark is unused (Pizzi, 2008; Miranda *et al*., 2012; Feng *et al*., 2013; Kemppainen *et al*., 2014)

Already in 1970s, several researchers dealt with the usability of bark for particleboards. Aaron (1973, cited in Muszynski and McNatt, 1984) determined that up to 10 % bark does not have a significant effect on particleboard properties. Lehmann and Geimer (1974); Muszynski and McNatt (1984), Nemli and Çolakoğlu (2005) determined a decrease in strength properties with the increased share of the bark. Muszynski and McNatt (1984) also determined the increase in thickness swelling and water absorption. Similar relation towards thickness swelling was determined by Blanchet *et al*. (2000), Ngueho Yemele *et al*. (2008). Regarding the bark and its impact on thickness swelling, Nemli and Çolakoğlu (2005) determined that the increase in bark share resulted in the decrease of thickness swelling. Ružiak *et al*. (2017) determined that the addition of the bark, as filler in plywood production, influences thickness swelling.

The purpose of this investigation is to show the effect of bark dust addition on thickness swelling, water uptake/absorption and internal bond of particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Pine (*Pinus sylvestris*) bark chips were used for the experiment. Bark chips (Figure 1) were crushed in a laboratory mill (Retsch SM2000) to obtain bark dust (Figure 2). The particles that passed through a sieve size of 0.237 mm were characterized as pine bark dust. The use of bark dust is related to the fact that using small bark particles results in better internal bonding (Ngueho Yemele *et al*., 2008; Marashdeh *et al*., 2011).

Wood particles (Figure 3) were produced from wood chips (softwood 40 % and hardwoods 60 %) using a laboratory chipper (Condux LT 61).

The size related structure of wood particles is presented in Table 1.

Since wet material was crushed, wood particles and bark dust needed to be dried prior to blending.

Figure 1 Pine bark chips
Slika 1. Iverje borovine

Figure 2 Pine bark dust
Slika 2. Drvna prašina napravljena od borovine

Figure 3 Wood particles
Slika 3. Drvne čestice

Table 1 Sieve analysis of wood particles
Tablica 1. Granulometrijski sastav usitnjenog drva

Sieve opening in mm *Otvor sita,* mm	**Share in %** *Udjel,* %
4.000	0.74
2.000	20.98
1.500	17.38
1.270	11.18
1.000	13.63
0.600	21.73
0.237	12.46
0 (bottom)	1.90

Table 2 Composition of laboratory made particleboards
Tablica 2. Sastav laboratorijski proizvedenih ploča iverica

Boards *Ploče*	**Share of wood** *Udjel drva* %	**Share of bark** *Udjel kore* %
A	100	0
B	99.5	0.5
C	99	1
D	95	5
E	90	10

Both constituents were dried for 16 hours at 70 °C to achieve moisture content less than 4 %.

Prior to blending, the appropriate amount of wood particles and bark dust was weighted (Table 2).

To produce single layer particleboards, melamine-urea-formaldehyde resin (Meldur H97) obtained from a local resin producer (Melamin Kočevje, Slovenia) was used.

The resin share was 11 % (dry resin weight/dry particles weight). The blending was done in a laboratory blender. Resin was sprayed through a nozzle. Total blending time was 6 minutes (3 minutes resin spraying and mixing and 3 minutes additional mixing). Afterwards, resinated material was hand formed into particle mat with dimensions 500×500 mm^2. The target thickness was 16 mm, and target density was 0.6 g/cm^3. The temperature of pressing was 200 °C, and the pressure was set to 3 N/mm^2. Total pressing time was 4 minutes.

After 7-day storage period, particleboards were cut into samples. The following properties were determined:
- Thickness and density (EN 323): sample size 50×50 mm^2, 6 samples
- Density profile: sample size 50×50 mm^2, 5 samples: density profile was determined using the density profile measurement device – Dense Lab X
- Moisture content (EN 322): sample size 50×50 mm^2, 4 samples
- Thickness swelling and water uptake after 24-hour immersion (EN 317): sample size 50×50 mm^2, 6 samples
- Thickness swelling and water uptake after exposure to humid environment: sample size 50×50 mm^2, 5 samples: Samples were exposed to humid environment (temperature 20 °C, relative air humidity 85 %) for 28 days
- Internal bond (IB) strength: sample size 50×50 mm^2, 6 samples: samples were glued on 18 mm beech plywood blocks using a hot melt adhesive applied by hot melt gun (EN 319).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The presence of bark dust in boards influenced their thickness compared to control boards (without bark dust) (Table 3).

Significant differences between boards with and without bark dust were observed in moisture content ($p<0.05$), while regarding density, the difference was statistically significant ($p<0.05$) only in boards with the highest bark dust share. Similar differences as those determined for board density can be seen more clearly in density profiles (Figure 4).

Density profile shows the negative aspect of using bark dust. The lower part of the board is on the right, while the upper surface layer is on the left. The structure of particles enables the migration of dust particles towards the lower board section. That migration causes board asymmetry due to differences in the board upper and lower density. In boards with bark dust such asymmetry is more pronounced due to a higher share of dust particles.

Although Lehmann and Geimer (1974); Muszynski and McNatt (1984), Nemli and Çolakoğlu (2005) found that strength properties decreased with the increase of bark share, the results of internal bond strength (Figure 5) test show that the addition of bark dust causes both the increase (lower bark share) and decrease of IB (higher bark share).

The internal bond values achieved support the findings of Ngueho Yemele *et al*. (2008), Marashdeh *et al*. (2011), since the highest internal bond strength was determined in the particleboard with 1 % bark dust. Statistically significant differences were determined between particleboards produced by adding 1 %, 5 % and 10 % bark dust. Despite the higher density of the board and the board core layer with 10 % bark dust, the IB strength was lower compared to the control board

Table 3 Thickness, density and moisture content based on board composition (values in brackets represent standard deviation)
Tablica 3. Debljina, gustoća i sadržaj vode za određeni sastav ploče (vrijednosti u zagradama označavaju standardnu devijaciju)

Board *Ploča*	**Composition (wood %/bark %)** *Sastav ploče (udjel drva/udjel kore)*	**Thickness** *Debljina* mm	**Density** *Gustoća* kg/m^3	**Moisture content** *Sadržaj vode* %
A (control)	100/0	15.57 (0.108)	604 (45.211)	9.0 (0.094)
B	99.5/0.5	15.31 (0.074)	649 (48.998)	9.1 (0.082)
C	99/1	15.51 (0.098)	626 (52.448)	9.3 (0.141)
D	95/5	15.43 (0.015)	639 (18.260)	9.3 (0.118)
E	90/10	15,67 (0.119)	683 (38.253)	9.3 (0.073)

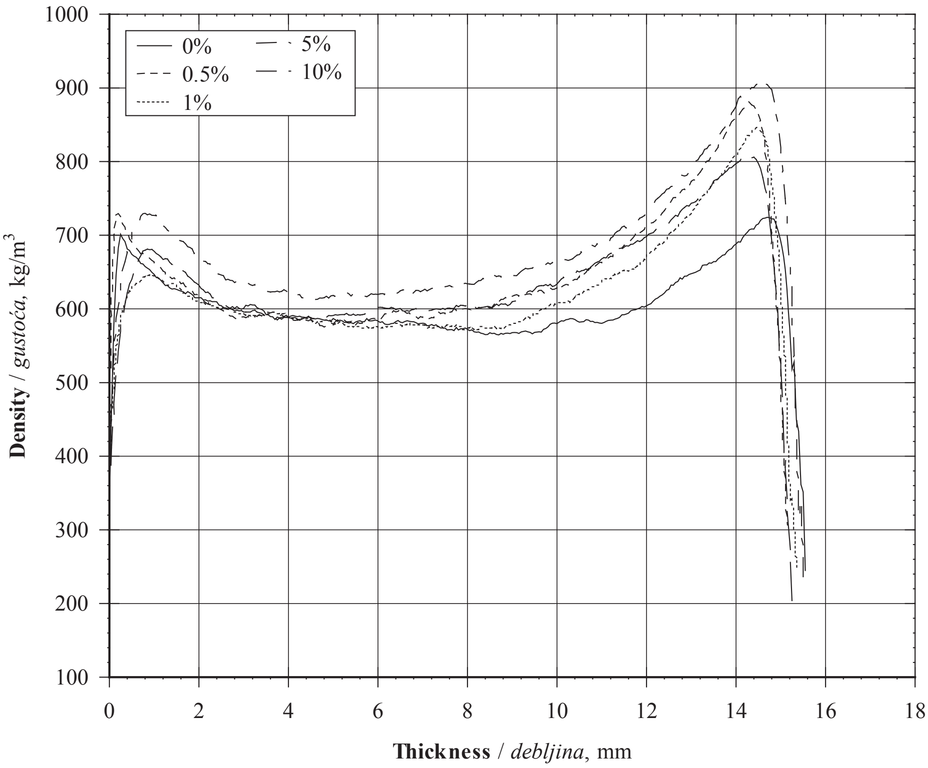

Figure 4 Density profile depending on bark share
Slika 4. Profil gustoće ploča u ovisnosti o udjelu kore

indicating the negative impact of higher bark share. According to Blanchet *et al*. (2000), the reason for lower internal bond strength of bark-based particleboards is related to lower bonding ability of blended bark particles compared to wooden particles, and to decreased heat transfer rate in boards with higher bark share (indicating thermal insulation properties of the bark).

The effect of bark dust on thickness swelling of particleboard is shown in Figure 6 and Figure 7.

The analysis of the results after immersion in water (α=0.05) showed significant difference between the con-

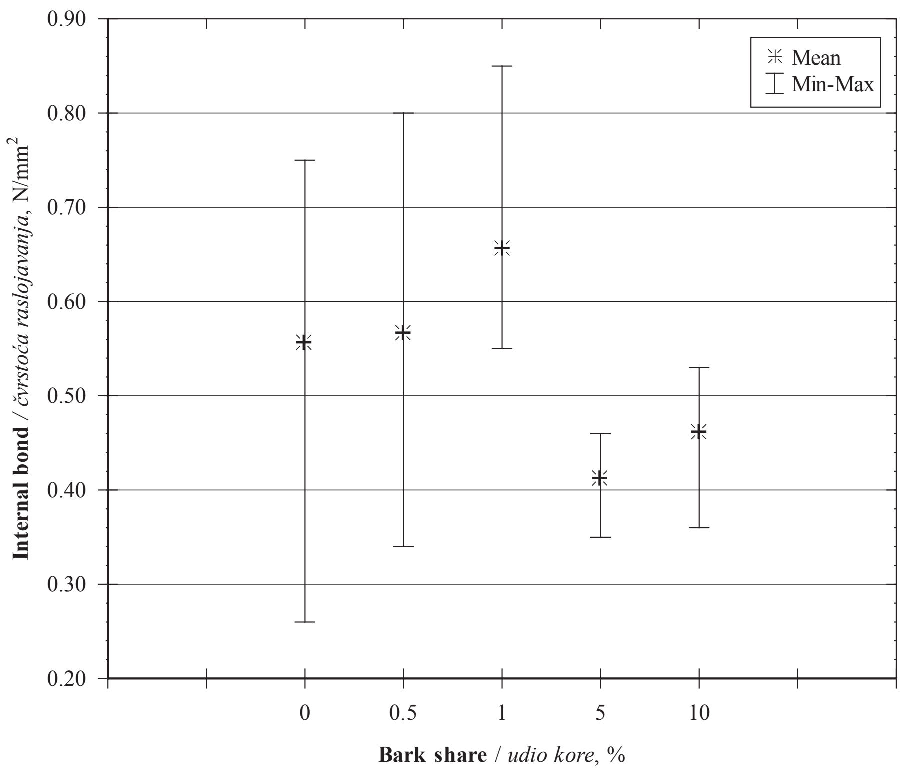

Figure 5 Internal bond strength depending on bark share
Slika 5. Čvrstoća raslojavanja ploča u ovisnosti o udjelu kore

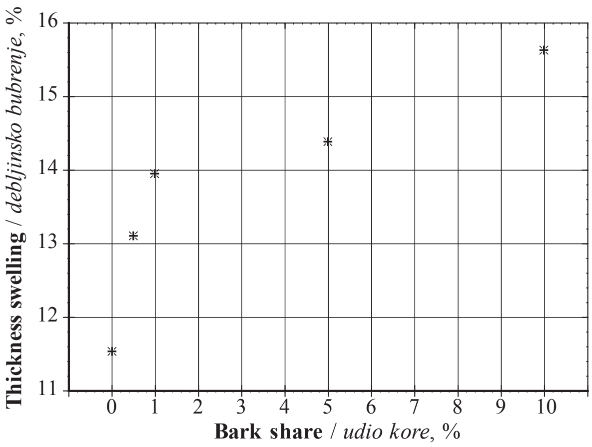

Figure 6 Thickness swelling after 24-hour immersion in water depending on bark share
Slika 6. Debljinsko bubrenje ploča nakon 24-satnog potapanja u vodi u ovisnosti o udjelu kore

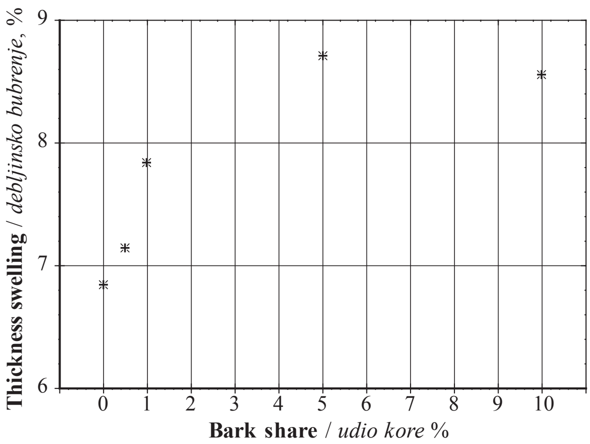

Figure 7 Thickness swelling after exposure to humid environment depending on bark share
Slika 7. Debljinsko bubrenje ploča nakon izlaganja vlažnim uvjetima u ovisnosti o udjelu kore

trol board (0 % dust) and the board with bark dust added. When comparing the values of thickness swelling of the boards with bark dust added, there is a significant difference between boards with 10 % bark and others, while there is little or no significant difference between boards with 0.5 %, 1 % and 5 % bark addition (p value > 0.05).

The increase in bark share resulted in the increase in thickness swelling after 24-hour immersion in water, although the increase is not linear. The initial difference (at 0.5 % bark share) was almost 15 %, while at bark share of 10 %, the difference in thickness swelling was 35 %.

At exposure to humid environment, the significant difference occurred between control boards and the board with 0.5 % bark compared to boards with 1 %, 5 % and 10 %. No significant difference was observed when comparing the thickness swelling of boards with 5 % and 10 % bark share (p value > 0.05). Lower thickness swelling of the board with 10 % bark share (compared to boards with 5 % bark share) could be related to higher density observed in boards with 10 % bark share. Higher board density results in higher resistance against water absorption, and hence slower water absorption and lower thickness swelling. The highest increase rate at exposure to humid environment occurred when the bark share was raised to 1 % (almost 15 %) and 5 % (almost 28 %).

The main reason for the negative effect of bark is due to bark natural swelling potential, which is higher than that of wood (Martin and Crist 1968). The in-

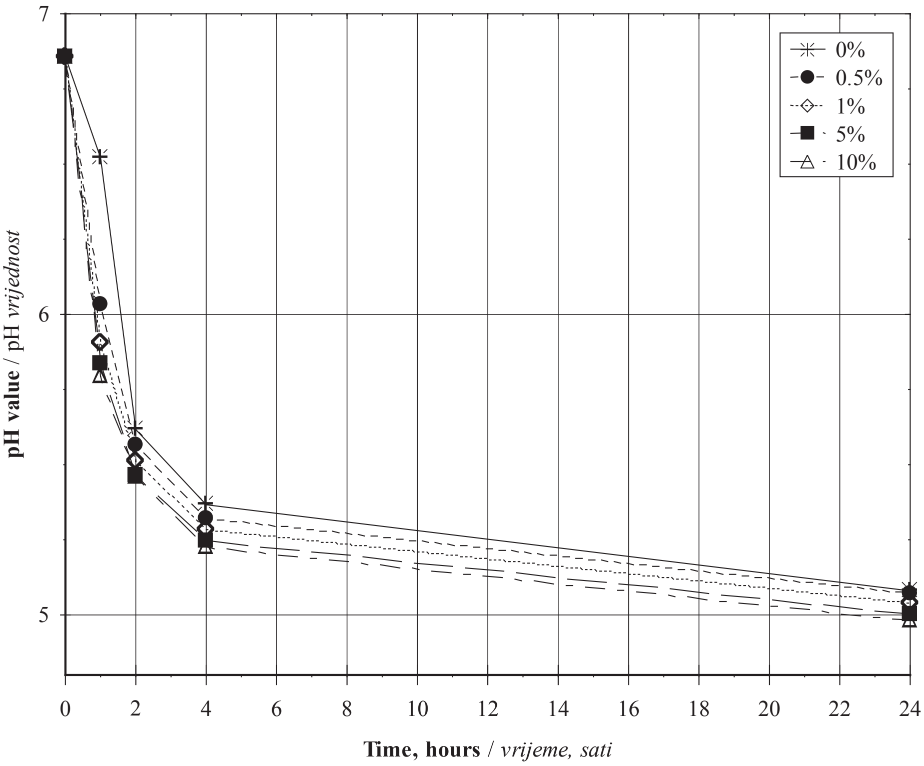

Figure 8 pH value change during immersion in water
Slika 8. Promjena pH vrijednosti tijekom potapanja ploča u vodi

crease in swelling with increasing bark share was also determined by Nemli and Colakoglu (2005). Another reason for swelling is related to stress relaxation (swelling of particles and regaining original position prior to pressing) of wooden and bark-based particles, which also causes the failure of bonds between particles.

A possible reason for higher thickness swelling in boards with higher bark share (at water immersion) could be related to the change of water pH-value that occurs during immersion in water (Figure 8).

The initial pH-value was similar for all board variations (6.86). After 24-hour immersion, the decrease in pH-value depended on the share of bark dust in the board. The highest decrease was observed in boards with the highest share of bark dust (1.87), and the lowest in boards without bark dust and with 0.5 % bark dust (1.78).

The change in water pH-value and increase in thickness swelling indicate that, during exposure to water, the failure of bond line occurs due acid conditions.

The change in the sample mass due immersion in water (water uptake) or exposure to humid environment (water absorption) is presented in Figure 9 and Figure 10.

In both cases, the change in mass was higher in boards without bark (control boards), while the addition of bark resulted in lower water uptake/absorption, although the differences were not significant when the boards were exposed to humid conditions. Lower water uptake after 24-hour immersion was also determined by Dost (1971).

Comparing the results of water uptake/absorption (Figure 9 and Figure 10) and thickness swelling (Figure 6 and Figure 7), it can be seen that bark particles, although absorbing less water than wooden particles, do swell more, which was also reported by Martin and Crist 1968 and Nemli and Colakoglu (2005).

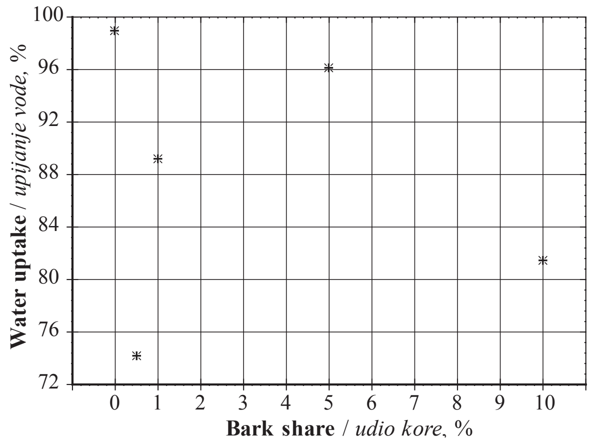

Figure 9 Water uptake after 24-hour immersion in water depending on bark share
Slika 9. Upijanje vode ploča nakon 24-satnog potapanja u vodi u ovisnosti o udjelu kore

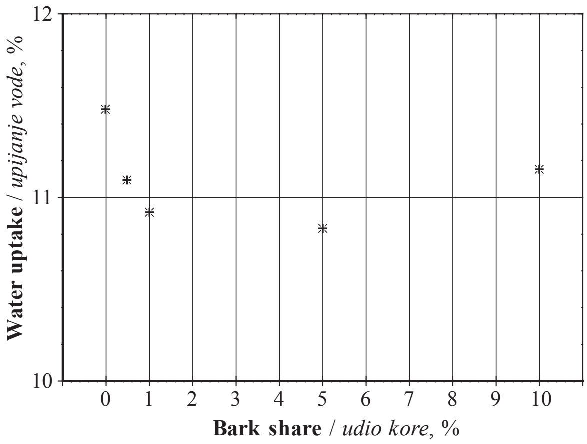

Figure 10 Water absorption after exposure to humid environment regarding the bark share
Slika 10. Upijanje vode ploča nakon izlaganja vlažnim uvjetima u ovisnosti o udjelu kore

4 CONCLUSIONS
4. ZAKLJUČAK

The availability of bark is relatively high since it is not used for wood-based products. In this study, bark dust was used as material that could partially substitute wood particles in particleboards. Although bark content was below 10 %, the effect of bark use was visible in internal bond and thickness swelling.

At bark content of up to 1 %, an increase (+18 %) in internal bond was determined, while higher bark content resulted in lower internal bond (-26 %).

The increase in bark content resulted in the increase of thickness swelling, while water uptake/absorption was lower (compared to boards without bark).

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