THERMAL CONDUCTIVITY OF DIFFERENT BIO-BASED INSULATION MATERIALS

TOPLOTNA PREVODNOST RAZLIČNIH BIO-IZOLACIJSKIH MATERIALOV

Sergej Medved[1], Eugenia Mariana Tudor[2], Marius Catalin Barbu[3], Timothy M. Young[4]

─── **Abstract / Izvleček** ───

Abstract: *To achieve the zero-waste goal as well as sustainability, the use of the raw materials, especially those from nature, and wood in particular, has to be smart, meaning that the resource has to be used to its full potential. Since wood-based industry is associated with high intensity and the generation of a relatively large amount of residues, those residues should be used for the production of useful products, otherwise they will easily be classified as waste and afterwards used as a source of energy. To present a possible solution for wood residues like wood chips, wood particles and bark, we investigated the possibility of using wood and bark residues as constituents for the production of single layer insulation panel with a target thickness of 40 mm and target density of 0.2 g·cm^{-3}. Thermal conductivity was determined using the steady state principle at three different temperature settings. The average thermal conductivities were determined between 49 mW·m^{-1}·K^{-1} and 74 mW·m^{-1}·K^{-1}. The highest values were determined at boards made from bark, which also had the highest density (0,291 g·cm^{-3}), while the lowest thermal conductivity was observed for boards made from spruce wood particles.*

Keywords: *thermal conductivity, insulation, particleboard, wood particles, bark*

Izvleček: *Doseganje cilja „nič odpadkov" in načela trajnostne rabe je kompleksen proces, ki zahteva učinkovito rabo surovine, še posebej naravne, zlasti lesa. Pomembno je, da je raba surovine celostna, da se uporabi v celoti za izdelavo trajnostnih produktov. Lesnopredelovalna industrija je visoko intenzivna proizvodnja, kar pomeni, da pri tem nastanejo tudi velike količine ostankov, primernih za izdelavo uporabnih proizvodov. V primeru, ko ostankov ne bi smotrno uporabili, pa se to surovino opredeli kot odpadek in uporabi za proizvodnjo energije (kar pa ni najbolj trajnostna in tudi optimalna rešitev). S ciljem predstavitve možne uporabe lesnih ostankov, kot so npr. sekanci, iveri in skorja, smo raziskali možnost njihove uporabe za izdelavo enoslojnih izolacijskih plošč ciljne debeline 40 mm in gostote 0.2 g·cm^{-3}. Toplotno prevodnost smo določili pri treh različnih temperaturnih pogojih. Ugotovljene vrednosti povprečne toplotne prevodnosti so bile med 49 mW·m^{-}1·K^{-1} in 74 mW·m^{-}1·K^{-1}. Najvišje vrednosti so bile izmerjene pri ploščah iz skorjete so imele tudi najvišjo gostoto (0.291 g·cm^{-3}), najnižje pa so izmerili na ploščah iz smrekovih iveri.*

Ključne besede: *toplotna prevodnost, izolativnost, sekanci, iveri, skorja*

[1] Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo, Jamnikarjeva 101, 1000 Ljubljana, SLO
* e-mail: sergej.medved@bf.uni-lj.si
[2] Forest Products Technology and Timber Construction Department, Salzburg University of Applied Sciences, Kuchl, Austria; Transilvania University of Brasov, Brasov, Romania;
[3] Forest Products Technology and Timber Construction Department, Salzburg University of Applied Sciences, Kuchl, Austria; Transilvania University of Brasov, Faculty of Furniture Design and Wood Engineering, Brasov, Romania
[4] The University of Tennessee Institute of Agriculture, Department of Forestry, Wildlife and Fisheries, Center for Renewable Carbon, Knoxville, Tennessee, USA

1 UVOD
1 INTRODUCTION

One of the important advantages of wood and wood-based industry is its ability to utilize the whole potential of this material created by nature. Trees are perennial plants with roots, stems and branches, and the wood that we get from tree stems is one of the best materials for sustainable development. But when considering sustainable development, the circular economy and zero waste society, there is still much more we can do with wood, as a significant amount of the tree stays unused or its usability is limited,

and thus is wasted or burned, with the latter causing the emission of greenhouse gasses, and thus pollution.

Particleboard made from wooden particles can be classified as a thermal insulating material. Sonderegger and Niemz (2009) reported a thermal conductivity value for three-layer particleboard between 99 mW·m^{-1}·K^{-1} and 118 mW·m^{-1}·K^{-1} (density between 0.62 and 0.76 g·cm^{-3}).

The availability of reports on the usability of wood chips for thermal insulation is limited. Wang and Fukuda (2016) presented the possibility of using vinyl packed wood chips as "loose-fill" insulation material for roofs. Skogsberg and Lundberg (2005) showed the positive impact of wood chips in order to prevent snow melting when snow is used as a cooling agent.

The most unused part of a tree is also the part that is most visible, the bark, which serves as a protective barrier for wood. Bark constitutes between 10% and 20% of total tree mass, although this varies regarding wood species and age of tree. Bark is the outer part of a tree occurring outside of the vascular cambium and can be divided into outer bark (dead tissue) and inner part (tissue with living cells). The majority of harvested bark is currently used for energy, which is, according to Deppe and Hoffmann (1972) and Gupta et al. (2011), not the best solution due its low calorific value and high CO_2 emissions. A smaller amount of bark is used in special applications like horticulture (for landscaping), in pharmacy (Miranda et al., 2012), for leather tanning (Pizzi, 2008), for insulation panels (Kain et al., 2014), foams (Tondi & Pizzi, 2009; Čop et al., 2015), decorative panels for flooring (Tudor et al., 2018), or as a substance to produce fire-resistant wood-based composites for construction purposes (Tondi et al., 2014). Most of the bark obtained in the debarking process in the forest or at a sawmill is unused, however, which creates an industrial and environmental problem. The complex structure of bark presents a problem when considering its usage, but it also opens wide range of possible approaches. In the literature some information can be found about utilizing bark for particleboards, with such work presented by Dost (1971), Deppe and Hoffman (1972), Maloney (1973), Lehmann and Geimer (1974), Place and Maloney (1977), Muszynski and McNatt (1984), Suzuki et al. (1994), Blanchet et al. (2000), Nemli and Colakoglu (2005), and Yemele et al. (2008). Despite the use of different adhesives, they determined that excessive bark content in the particleboard lowers mechanical properties and resistance against water (increases thickness swelling and water uptake). Ružiak et al. (2017) used bark as a filler (a flour substitute) and also determined its influences on thickness swelling. The main reason for such behaviour was due to differences in the size of constituents and the chemical structure of bark compared to wood. The chemical composition of bark shows that it contains a higher content of ash, extractives and lignin, and a lower content of polysaccharides cellulose and hemicelluloses (Antonović et al., 2010; Antonović et al., 2018). Due to the presence of phenol like components in bark, which react with formaldehyde (Cameron & Pizzi, 1985; Prasetya & Roffael, 1991; Nemli & Çolakoğlu, 2005; Takano et al., 2008; Medved et al., 2019), the addition of bark resulted in lower formaldehyde emissions. Bark, although an underutilized bio- or lignocellulose-based resource, is also a very interesting material, which has a versatile role in the tree. As summarized by Rossel et al. (2014), the main functions of bark are protection, transportation and storage of nutrients, insulation, and mechanical support of the stem. Due to undesired particle morphology and the fact that a lot of dirt, stones, and other unwanted contaminants, picked up during logging, can have a negative impact on processing, bark has generally been of low interest for wider industrial use, especially for the production of wood-based panels (Deppe & Hoffman, 1972; Pásztory et al., 2016).

The utilization of bark relies mostly on its physical and chemical properties, hence it is no surprise that the majority of reports in last decade(s) are focused on using bark as insulation material (Martin, 1963; Suzuki et al., 1994; Sato et al., 2009; Kain et al. 2014).

Martin (1963) determined that dry bark has almost 20% better insulation properties than solid wood at the same density, and that the conductivity of boards made from bark was lower than that obtained for boards made from wood.

The usage of low quality wood is nowadays mostly related to particleboard and fibreboard production, and also with energy production, while bark is used mostly for energy. In the present investigation we focus on an important wood property, on its thermal insulation ability. Wood and bark residues created by the wood processing industry are mostly in already crushed shape, meaning they are either in shape of particles or chips. The aim of this paper is thus to present the possibility to using wood and bark residues for the production of boards with low thermal conductivity.

2   MATERIALS AND METHODS
2   MATERIALI IN METODE DELA

To carry out this study Norway spruce (*Picea abies* Karst.) residues and a mixture of coniferous barks were used. Solid wood and bark were processed in a laboratory using a Prodeco M-0 chipper (Figure 1) with an output screen with openings of 25 mm in diameter, along with a Condux CSK 350/N1 ring chipper (Figure 2), with the gap between the blade and beating bar of 1.25 mm.

A ring chipper was used only to obtain wood particles (Figure 3a), while a chipper was used for the primary breakdown of wood (Figure 3b) and bark (Figure 3c).

The resulting constituents were dried at 70°C for 16 hours to achieve a moisture content below 4 %. After drying, an appropriate mass of particles was put into a blending machine, where the particles were blended with melamine-urea-formaldehyde adhesive (blending ratio 15%, solid/solid ratio) produced by Melamin Kočevje, Slovenia. The total blending time was 10 minutes (5 minutes adhesive spraying and mixing + 5 minutes only mixing). Blended particles were then hand formed into

Figure 1. Prodeco M-0 chipper
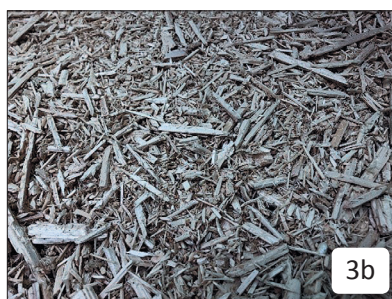*Slika 1. Prodeco M-0 sekirostroj*

Figure 2. Condux CSK 350/N1 ring chipper
Slika 2. Condux CSK 350/N1 obročasti iverilnik

Figure 3. Constituents used in the investigation (spruce wood particles (3a), spruce wood chips (3b) and coniferous bark (3c))
Slika 3. Gradniki, uporabljeni v raziskavi (iveri lesa smreke (3a), sekanci lesa smreke (3b) in skorja iglavcev (3c))

a frame with the dimensions 500×500 mm^2 (Figure 4), which was placed on a steel plate.

The target density of the produced panels was 0.2 g·cm^{-3}, with a thickness of 40 mm. The mat was pressed at 180°C and a pressure of 2 N·mm^{-2}.

The pressing time was set to 9 minutes followed by a 1 minute degassing phase. Three boards per composition were made.

The boards were then left at room conditions to cool down (for 60 minutes), and later placed in

Figure 4. Wood and bark mat before pressing
Slika 4. Natreseni gradniki lesa in skorje pred stiskanjem

a climate chamber at a temperature of 23±1°C and 55±5% relative air humidity. After 21 days the thermal conductivity of the boards was measured.

Thermal conductivity was determined according to EN 12667, 2002 in an LM.305 heat flow meter (Stirolab, Sežana, Slovenia). The technique used is based on the measuring of the heat conductivity in the heating chamber until steady state conditions are achieved. The measuring area was 290×260 mm². The measurements were conducted at three different conditions, as shown in Table 1.

The determination of heat conductivity lasted 240 minutes. Thermal conductivity λ in W·m⁻¹·K⁻¹ was calculated according to equation 1.

$$\lambda = \frac{t \times Q}{S \times \Delta T} \quad [1]$$

where t is the thickness of sample in m, Q is the generated heat flow in W (for upholding steady state conditions – linear temperature gradient), S is the sample surface area in m² and ΔT is the temperature difference between hot and cold sides in K.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

The thickness and density of the produced boards depends on the board composition (Table 2).

Even though all boards had same target density and thickness it can be observed that there were differences between the boards. The differences in thickness and density between boards made from wood chips and wood particles are due the differences in the compressibility of the constituents (bigger constituents, i.e. chips, being less compressible, and hence a higher thickness and lower density). The higher density and lower thickness of bark board could be the result of the reaction during compression, and thus it can be assumed that bark constituents were damaged (crushed and broken) during pressing, which enabled repositioning of the crushed parts into voids, hence creating a higher density. This higher density bark board also resulted in higher thermal conductivity, and so lower resistance against heat conductivity (Figure 5).

Comparing the density values (Table 2) and thermal conductivity (Figure 5) reveals a correlation, and namely that an increase in density causes

Table 1. Thermal conductivity measurements settings
Preglednica 1. Merilna območja za določanje toplotne prevodnosti

	Lower plate / Spodnja plošča	Upper plate / Zgornja plošča	Average temperature / Povprečna temperatura	Temperature difference / Temperaturna razlika
	°C	°C	°C	K
Set 1 / Območje 1	10	20	15	10
Set 2 / Območje 2	10	35	22.5	25
Set 3 / Območje 3	10	50	30	40

Table 2. Thickness and density of the produced boards
Preglednica 2. Debeline in gostote izdelanih plošč

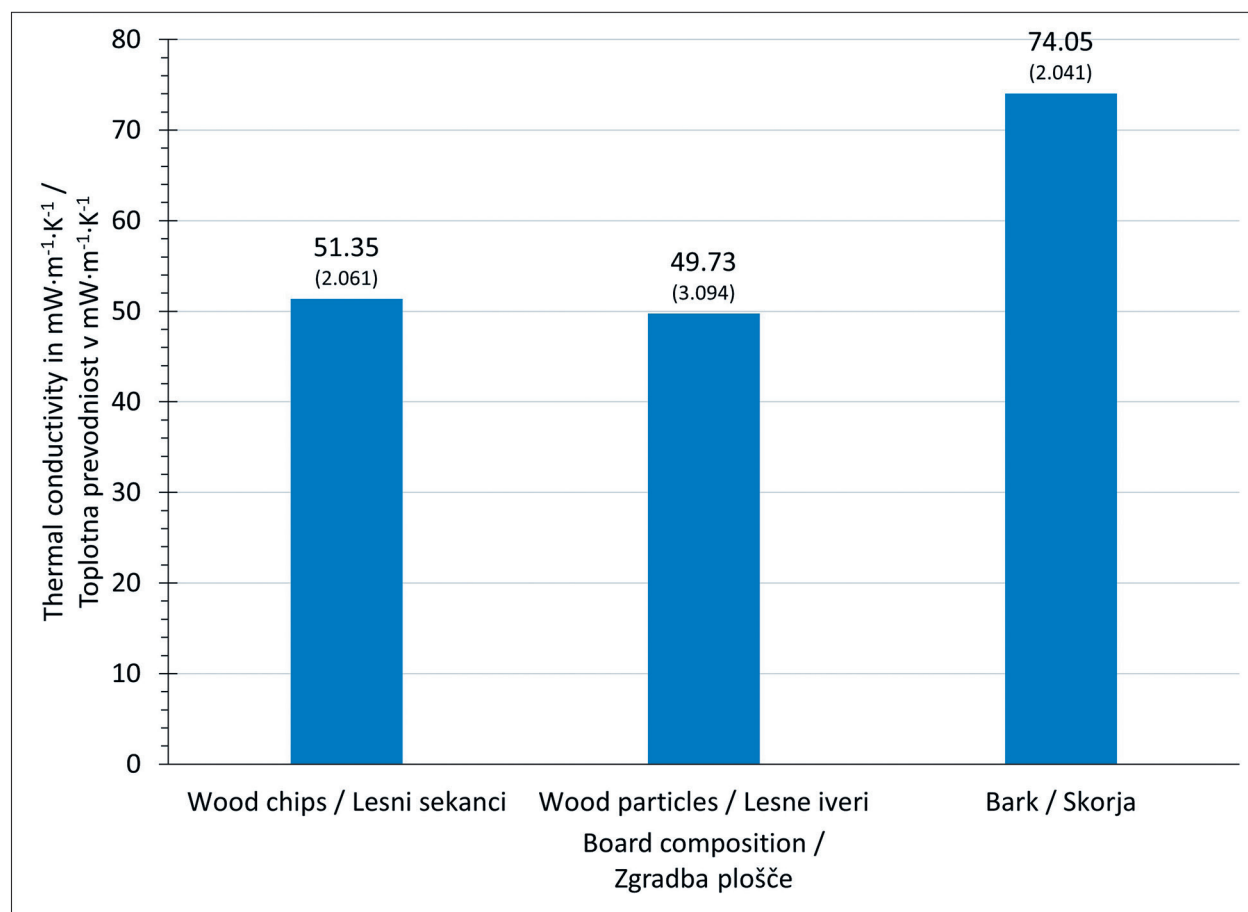|	Thickness / Debelina	Density / Gostota
	mm	g·cm⁻³
Wood chips / Lesni sekanci	42.42	0.232
Wood particles / Lesne iveri	42.01	0.252
Bark / Skorja	37.06	0.291

Figure 5. Average thermal conductivity with regard to the board composition (numbers in parentheses represent standard deviation values)
Slika 5. Povprečne vrednosti toplotne prevodnosti glede na zgradbo plošče (vrednosti v oklepajih so vrednosti standardnih odklonov)

an increase in thermal conductivity. The increase in thermal conductivity of denser materials is related to the higher number of constituents in contact with each other and lower number of "air" filled voids, which present a barrier to heat conductivity, while constituents in contact conduct heat from hot towards cold areas. Heat transfer will occur when the area in question reaches the maximum potential (with regard to neighbouring conditions), and the area next to it is cooler and able to accept the energy. When all areas are heated to maximum potential (according to available conditions) permanent heat flow occurs, and that flow also means a loss in energy. Higher thermal conductivity was also observed in the board made of wood chips (compared to wood particles),
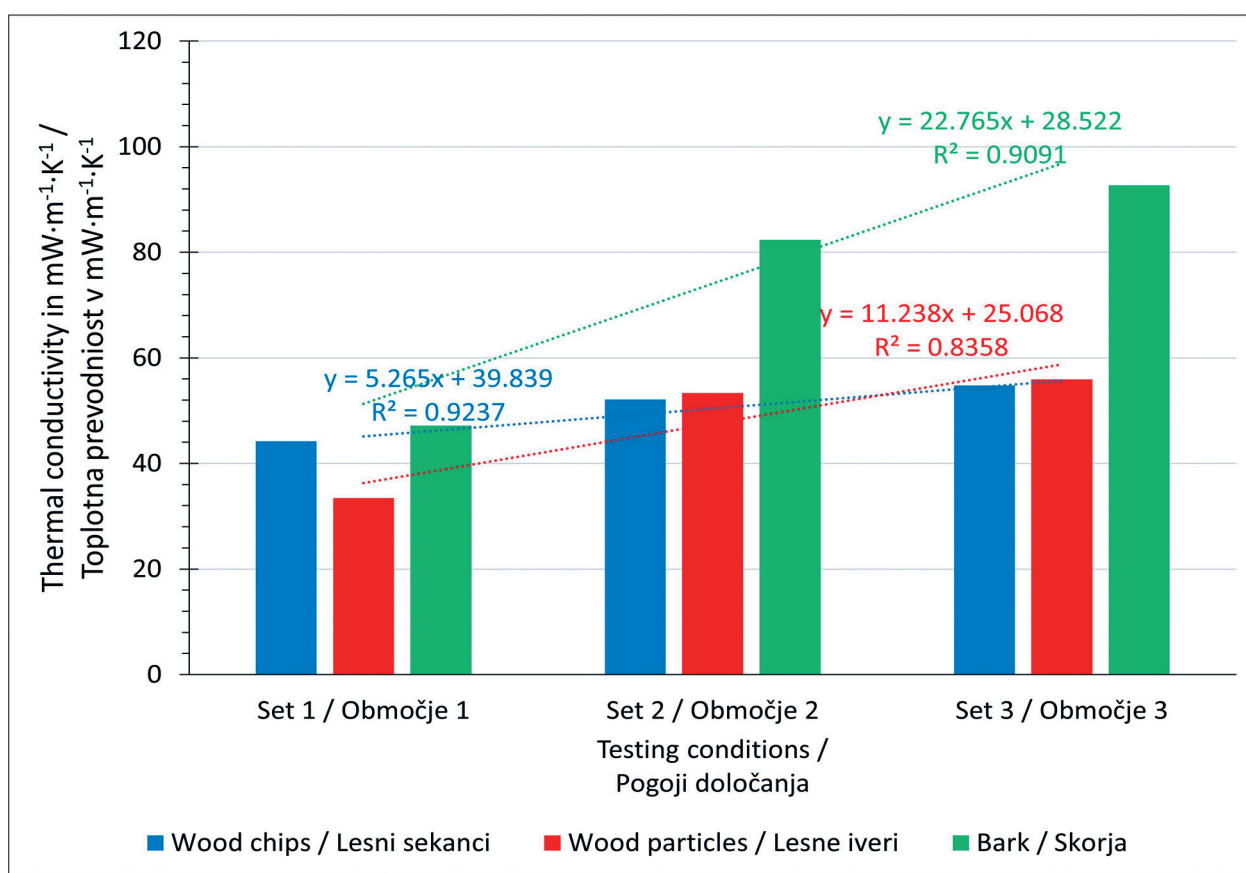
Figure 6. Thermal conductivity with regard to board composition and testing conditions
Slika 6. Toplotna prevodnost glede na zgradbo plošče in pogoje določanja toplotne prevodnosti

which could be related to the constituents' morphology. Although "stacking" bigger constituents leaves larger voids, those larger voids do not help much in lowering thermal conductivity. This is because bigger constituents enable the creation of bigger contact areas between constituents, which results in more efficient heat transfer.

A detailed analysis of the boards' behaviour at different settings shows more clearly the difference, especially between boards from wood-based constituents (Figure 6).

In all boards, the increase in average temperature/temperature differences resulted in an increase in thermal conductivity, but when comparing the relations related to board composition it reveals that boards made from wood chips are less influenced by the change in temperature conditions, while bark boards show higher sensitivity towards an increase in temperature.

Since heat resistance is determined as the relation between thickness and thermal conductivity,

there is no surprise that the lowest resistance was recorded in boards containing bark (Table 3), supporting the earlier observations that bigger constituents and higher density offer lower heat flow resistance.

Table 3. Heat resistance of the produced boards (the numbers in parentheses represent standard deviation values)
Preglednica 3. Toplotna upornost izdelanih plošč (v oklepajih so vrednosti standardnih odklonov)

	Heat resistance / Toplotna upornost
	$m^2 \cdot K \cdot W^{-1}$
Wood chips / Lesni sekanci	0.84 (0.047)
Wood particles / Lesne iveri	0.88 (0.084)
Bark / Skorja	0.55 (0.033)

4 CONCLUSIONS
4 SKLEPI

An analysis of the different residues (chips, particles, bark) shows that it is possible to make a stable board with densities between 0.23 g·cm^{-3} and 0.29 g·cm^{-3} for insulation purposes. The highest thermal conductivity values and the lowest heat resistance were determined in bark boards. The highest insulation effect was found when wood (spruce) particles were used, but the sensitivity towards the testing conditions was lowest in boards made from wood (spruce) chips.

5 SUMMARY
5 POVZETEK

Pomembna prednost lesnopredelovalne industrije je sposobnost izkoriščanja celostnega potenciala lesa kot dragocene naravne surovine. Celostna raba naravnih virov je pomemben vidik krožnega gospodarstva, nizkoogljične družbe in družbe z „nič odpadki". Čeprav je področje rabe lesa zelo široko, od različnih proizvodov iz masivnega lesa do različnih lesnih ploščnih kompozitov, pa vseeno opažamo, da relativno velika količina lesa ostane neuporabljenega oz. njegov celotni potencial ni izkoriščen. Številne raziskave pričajo o možnostih rabe lesnih ploščnih kompozitov ne samo za izdelavo pohištva ali nosilnih konstrukcijskih elementov ampak tudi za izdelavo izolacijskih materialov (Sonderegger & Niemz, 2009; Wang & Fukuda, 2016; Skogsberg & Lundberg, 2005), pri čemer so bile plošče oz. izolatorji izdelani iz iveri ali pa iz sekancev. Skupina avtorjev pa je za izdelavo izolatorjev uporabila tudi skorjo (Martin, 1963; Suzuki et al., 1994; Sato et al., 2009; Kain et al., 2014).

Uporaba lesne surovine slabše kakovosti je danes omejena predvsem na izdelavo ivernih in vlaknenih plošč oz. na proizvodnjo energije, medtem ko se skorja uporablja predvsem kot energent. Ker se tako les kakor tudi skorja nahaja že v zdrobljeni obliki (sekanci, iveri), je cilj pričujoče raziskave predstaviti možnost rabe takšne surovine za izdelavo izolacijskih plošč.

Za izdelavo izolacijskih plošč smo uporabili lesne ostanke navadne smreke (*Picea abies* Karst.) in skorjo iglavcev, ki smo jo predelali v sekance oz. iveri na laboratorijskem sekirostroju Prodeco M-0 in laboratorijskem obročastem iverilniku Condux CSK 350/N1. Izdelane gradnike smo nato pri temperaturi 70 °C posušili do vlažnosti pod 4 %, čemur je sledilo oblepljanje z melamin-urea-formaldehidnim lepilom (delež lepila 15 %). Oblepljene gradnike smo nato ročno natresli v lesen okvir z dimenzijami 500 × 500 mm^2. Ciljna debelina plošč je bila 40 mm, ciljna gostota pa 0.2 g·cm^{-3}. Stiskali smo 9 minut pri temperaturi 180 °C in tlaku 2 N·mm^{-2}. Po 21dnevni klimatizaciji pri normalnih pogojih (temperaturi 23±1 °C in 55±5 % relativni zračni vlažnosti) smo določili toplotno prevodnost plošč po standardu EN 12667, 2002. Toplotno prevodnost smo določili pri treh različnih pogojih in sicer:

- ΔT10: temperatura spodnje plošče 10 °C, temperatura zgornje plošče 20 °C
- ΔT25: temperatura spodnje plošče 10 °C, temperatura zgornje plošče 35 °C
- ΔT40: temperatura spodnje plošče 10 °C, temperatura zgornje plošče 50 °C

Meritev je trajala 240 minut.

Debelina izdelanih plošč je bila 37,06 mm (skorja), 42,01 mm (iveri) oz. 42,42 mm (sekanci), gostota pa 0.232 g·cm^{-3} (sekanci), 0.252 g·cm^{-3} (iveri) oz. 0.291 g·cm^{-3} (skorja) (preglednica 2). Tudi toplotna prevodnost je odvisna od zgradbe plošče oz. velikosti uporabljenih gradnikov. Pri plošči, izdelani iz smrekovih sekancev, je bila povprečna toplotna prevodnost 51.35 mW·m^{-1}·K^{-1} (44.23 mW·m^{-1}·K^{-1} pri ΔT10; 55.12 mW·m^{-1}·K^{-1} pri ΔT25 in 54.76 mW·m^{-1}·K^{-1} pri ΔT40), iz smrekovih iveri 49.73 mW·m^{-1}·K^{-1} (33.43 mW·m^{-1}·K^{-1} pri ΔT10; 53.30 mW·m^{-1}·K^{-1} pri ΔT25 in 55.91 mW·m^{-1}·K^{-1} pri ΔT40) in pri skorji 74.05 mW·m^{-1}·K^{-1} (47.13 mW·m^{-1}·K^{-1} pri ΔT10; 82.37 mW·m^{-1}·K^{-1} pri ΔT25 in 92.66 mW·m^{-1}·K^{-1} pri ΔT40). Ugotovili smo, da je toplotna prevodnost odvisna od velikosti uporabljenih gradnikov (manjša pri manjših gradnikih) ter gostote (večja pri ploščah z večjo gostoto). Raziskava je pokazala, da je mogoče iz različnih ostankov (lesnih sekancev, lesnih iveri in skorje) izdelati stabilne plošče z gostoto med 0.23 g·cm^{-3} in 0.29 g·cm^{-3}, ki se lahko uporabijo kot izolacijske plošče, saj je toplotna prevodnost nižja od 75 mW·m^{-1}·K^{-1}.

ACKNOWLEDGEMENT
ZAHVALE

REFERENCES
VIRI

Antonović, A., Jambreković, V., Franjić, J., Španić, N., Pervan, S., Ištvanić, J., & Bublić, A. (2010). Influence of sampling location on content and chemical composition of the beech native lignin (*Fagus sylvatica* L.). Periodicum Biologorum, 112(3), 327-332.

Antonović, A., Barčić, D., Kljak, J., Ištvanić, J., Podvorec, T., & Stanešić, J. (2018). The quality of fired Aleppo pine wood (*Pinus halepensis* Mill.). Biomass for Biorefinery Products. Croatian Journal of Forest Engineering, 39(2), 313-324.

Blanchet, P., Cloutier, A., & Riedl, B. (2000). Particleboard made from hammer milled black spruce bark residues. Wood Science and Technology, 34(1), 11-19.

Cameron, F. A., & Pizzi, A. (1985). Tannin-induced formaldehyde release depression in urea formaldehyde particleboard. In: Meyer, B., Kottes-Andrews, B. A., Reinhardt, R.M. (ed.), Formaldehyde Release from Wood Products. American Chemical Society Symposium Series, No. 316, Washington, DC, Chapter 15, pp 205.

Čop, M., Laborie, M. P., Pizzi, A., & Šernek, M. (2015). Curing characterisation of spruce tannin-based foams using the advanced isoconversional method. BioResources, 9(3), 4643-4655.

Deppe, H. J., & Hoffman, A. (1972). Particleboard experiments. Utilize softwood bark waste. World Wood 13(7), 8-10.

Dost, W. A. (1971). Redwood bark fiber in particleboard. Forest Products Journal, 21(10), 38-43.

Gupta, G., Yan, N., & Feng, M. W. (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.

Kain, G., Güttler, V., Barbu, M. C., Petutschnigg, A., Richter, K., & Tondi, G. (2014). Density related properties of bark insulation boards bonded with tannin hexamine resin. European Journal of Wood and Wood Products, 72, 417-424.

Lehmann, W. F., & Geimer, R. L. (1974). Properties of structural par-

ticleboards from Douglas-fir forest residues. Forest Products Journal, 24(10), 17-25.

Maloney, T. M. (1973). Bark boards from four west coast softwood species. Forest Products Journal, 23(8), 30-38.

Martin, R. E. (1963). Thermal properties of bark. Forest Products Journal, 13, 419-426.

Medved, S., Gajšek, U., Tudor, E. M., Barbu, M. C., & Antonović, A. (2019). Efficiency of bark for reduction of formaldehyde emission from particleboards. Wood Research, 64(2), 307-316.

Miranda, I., Gominho, J., & Pereira, H. (2012). Incorporation of bark tops in *Eucalyptus globulus* wood pulping. BioResources, 7(3), 4350-4361.

Muszynski, Z., & McNatt, J. D. (1984). Investigations on the use of spruce bark in the manufacture of particleboard in Poland. Forest Products Journal, 34(1), 28-35.

Nemli, G., & Colakoglu, G. (2005). Effects of mimosa bark usage on some properties of particleboard. Turkish Journal of Agricultural Forestry, 29(3), 227-230.

Pásztory, Z., Ronyecz Mohácsiné, I., Gorbacheva, G., & Börcsökr, Z. (2016). The Utilization of Tree Bark. BioResources, 11(3), 7859-7888.

Pizzi, A. (2008) Tannins: Major sources, properties and applications. In: Monomers, Polymers and Composites from Renewable Resources (1st ed.), Gandini, A., Naceur Belgacem, M., Elsevier, Oxford, pp 179-199.

Place, T. A., & Maloney, T. M. (1977). Internal bond and moisture response properties of three-layer, wood bark boards. Forest Products Journal, 27(3), 50-54.

Prasetya, B., & Roffael, E. (1991). Untersuchenegen über das Verhalten extraktstoffreicher Rinden in Holzspanplatten zur Reaktivität der Fichtenrinde gegenüber Formaldehyd. Holz als Roh- und Werkstoff, 49, 341-344.

Ružiak, I., Ignaz, R., Krišťak, L., Réh, R., Mitterpach, J., Očkajová, A., & Kučerka, M. (2017). Influence of urea-formaldehyde adhesive modification with beech bark on chosen properties of plywood. BioResources, 12(2), 3250-3264.

Sato, Y., Konishi, T., & Takahashi, A. (2009). Development of Insulation Material Using Natural Tree Bark. (2009, April, 2). Retrieved from http://techsrv.eng.utsunomiya-u.ac.jp/~yutaka/e-house/031007ICAM.pdf

Skogsberg, K., & Lundberg, A. (2005). Wood chips as thermal insulation of snow. Cold Regions Science and Technology, 43, 207–218.

Sonderegger, W., & Niemz, P. (2009). Thermal conductivity and water vapour transmission properties of wood-based materials. European Journal of Wood and Wood Products, 67, 313–321.

Suzuki, S., Saito, F., & Yamada, M. (1994). Properties of bark-wood particle composite board. Mokuzai Gakkaishi, 40(3), 287-292.

Takano, T., Murakami, T., Kamitakahara, H., & Nakatsubo, F. (2008). Formaldehyde absorption by karamatsu (*Lari leptolepis*) bark. Journal of Wood Science, 54, 332-336.

Tondi, G., & Pizzi, A. (2009). Tannin-based rigid foams: a survey of chemical and physical properties. Bioresource Technology, 100, 5162-5169.

Tondi, G., Haurie, L., Wieland, S., Petutschnigg, A., Lacasta, A., & Monton, J. (2014). Comparison of disodium octaborate tetrahydrate-based and tannin-boron-based formulations as fire retardant for wood structures. Fire and Materials, 38, 381-390.

Tudor, E. M., Barbu, M. C., Petutschnigg, A., & Réh, R. (2018). Added-value for wood bark as a coating layer for flooring tiles. Journal of Cleaner Production, 170, 1354-1360.

Wang, Y., & Fukuda, H. (2016). Timber Chips as the Insulation Material for EnergySaving in Prefabricated Offices. Sustainability 8, 587-599.

Yemele, M. C. N., Blanchet, P., Cloutier, A., & Koubaa, A. (2008). Effect of bark content and particle geometry on the physical and mechanical properties of particleboard made from black spruce and trembling aspen bark. Forest Products Journal, 58(11), 48-56.

EN (2002). Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance. (EN 12667: 2002)