Marta Pędzik[1,2], Zdzisław Kwidziński[2,3], Tomasz Rogoziński[2]

Particles from Residue Wood-Based Materials from Door Production as an Alternative Raw Material for Production of Particleboard

Iverje nastalo obradom drvnih materijala pri proizvodnji vrata kao alternativna sirovina za proizvodnju ploča iverica

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ABSTRACT • *Problems with the availability of particleboards are a challenge for constructors and production companies that use this material in the technology of their products. During the production process of technical door leaves, a significant amount of wood-based panel residues is created, which is a large base of potential raw material on an annual basis. Given the conceptual link between circular economy (CE) activities, resources, and waste management, efforts should be made to process and reuse them to produce new particleboards. The aim of the study was to determine the physical and hygienic properties of particles obtained from the grinding of lignocellulosic composites used in production. It was found that in terms of dimensions, density as well as formaldehyde content, they have the potential to be an alternative source of raw material for the production of particleboards. However, selecting the type of materials should be carried out, and in the future, the hygienic properties of the manufactured particleboards should be controlled.*

KEYWORDS: *door frame industry; particle properties; environmentally friendly; reuse; circular economy*

SAŽETAK • *Problemi s dostupnošću ploča iverica izazov su za građevinare i tvrtke koje se tim materijalom koriste u svojim proizvodnim tehnologijama. Tijekom proizvodnje vratnih krila stvara se znatna količina ostatka od obrade drvnih ploča, koji na godišnjoj razini čini potencijalno veliku sirovinsku bazu. S obzirom na konceptualnu vezu između aktivnosti kružne ekonomije (CE), resursa i gospodarenja otpadom, potrebno je uložiti napore kako bi se taj drvni ostatak obradio i ponovo iskoristio za proizvodnju ploča iverica. Cilj ovog istraživanja bio je utvrditi fizikalna svojstva i ekološku prihvatljivost iverja dobivenog u procesu obrade (glodanja) lignoceluloznih kompozitnih materijala. Utvrđeno je da po dimenzijama, gustoći i sadržaju formaldehida takvo iverje može biti alternativni izvor sirovine za proizvodnju ploča iverica. Međutim, potrebno je odabrati odgovarajuću vrstu materijala, ali i kontrolirati ekološka (higijenska) svojstva izrađenih ploča iverica.*

KLJUČNE RIJEČI: *proizvodnja vrata; svojstva iverja; ekološka prihvatljivost; ponovna uporaba; kružna ekonomija*

[1] Author is researcher at Poznań Institute of Technology, Łukasiewicz Research Network, Wood Technology Centre, Poznan, Poland. https://orcid.org/0000-0003-3607-8128
[2] Authors are researchers at University of Life Sciences, Faculty of Forestry and Wood Technology, Department of Furniture Design, Poznan, Poland. https://orcid.org/0000-0003-4957-1042
[3] Author is researcher at Porta KMI Poland S. A., Bolszewo, Poland. https://orcid.org.pl/0000-000208522-9650

1 INTRODUCTION
1. UVOD

Due to the numerous uses of wood in construction materials, packaging, transport, furniture and energy, rational use of wood has become an essential aspect of environmental protection. The amount of resources present in the environment is limited. In some industries, it is possible to wholly or partially replace wood with another raw material (Mohd Ali *et al*., 2020). An example of an adequate substitution of wood with alternative raw materials is the industry of wood-based panels, more specifically particleboards (Nurhazwani *et al*., 2016; Pędzik *et al.*, 2022).

Problems with the availability of particleboards are a challenge for constructors and production companies that use this material in the technology of their products. The annual global production of chipboard in 2020 amounted to over 96 million m^3, of which 40.5 million m^3 was European production (FAO, 2022). These data show that particleboard is an important material. The production volume of particleboard in 2020 was lower by approx. 9 % compared to 2015, and by approx. 5 % compared to 2018. Nevertheless, the decline in production is not due to the lack of interest and demand on the part of enterprises but is related to the raw material deficit. Therefore, research has been carried out for a long time to expand the raw material base for the particleboard industry. Due to the trend of the circular economy (CE) and recycling of materials, materials containing wood or other lignocellulosic particles, previously unused in industrial production, seem to be a large base of the raw material (Foti *et al*., 2022). Various sources have already been considered, i.e., wood residues and low-value woody species, plantations of fast-growing trees, or urban waste. Raw materials alternatives to wood are often by-products and residues from the agricultural and food industries, i.e., cereal straws, agricultural crops, food and agricultural wastes, hulls and husks of seeds and seaweeds (Pędzik *et al*., 2021). The undoubted advantage of using these raw materials is their renewable nature, ease of obtaining, and low price. They are not the main target of cultivation, so competition is much less.

Managing by-products is an important aspect when planning and designing production and using products (Azambuja *et al*., 2018). In many cases, from such raw materials, it is possible to produce good-quality boards that meet the requirements of technical standards, so it is necessary to look for other, new sources of raw materials. Therefore, using waste as a raw material for particleboard production can reduce the burden on producers with increasing production costs (Lee *et al*., 2018). What is a waste for one industry, for another maybe a valuable source of full-value raw material and at the same time contribute to the improvement of the condition and protection of the environment. Sustainable resource management means not only prudent sourcing of resources but also rational use of them. They are recycled in the form of waste and finished products (Foti *et al*., 2022). Due to the development and technological progress, guided by the idea of reusing raw materials, factories producing particleboards use a significant addition of post-consumer and recycled wood. The research proves that particleboards made, in the core layer, with 50 % content of particles from recycling boards glued with UF resin and laminated particleboards do not significantly deteriorate the properties of the panels (Czarnecki *et al*., 2003).

The amount of pure softwood particles in particleboards is already much less than a few years ago. Following trends and responding to market needs, more and more attention is paid to the use of waste and by-products. Particleboards are available to produce wood from forest thinning, saw waste, and recycled wood, including recycled wood for furniture, pallets, wooden packaging, and construction and demolition components (Azambuja *et al*., 2018).

One of the industries where a significant amount of particleboard is used is the production of joinery products. In the production plants of doors and door frames, a considerable amount of wood-based panel residues is generated during the production process. It is estimated that in a large production plant from the technical door leaf, there is an average of about 2.3 kg of waste, which generates about 10 tons during a two-shift production. On an annual basis, such an amount of waste is an expensive and considerable challenge to manage. At the same time, it is a good basis for valuable raw material. This waste is generated from materials used in the production of door leaves. These are wood composite materials composed of softwood, plywood, particleboard, HDF boards, MDF boards, and light filling boards containing HDF and paper honeycomb. These residues constitute a waste material from processing at various stages of production, i.e., formatting, drilling holes, milling, etc. Their dimensions depend on the type of technological operation and the specific shapes or patterns of milling the door leaves. Such amounts and composition cause problems with utilizing and managing these residues in production plants. They are subject to thermal conversion. Given the conceptual link between CE-compliant activities, resources, and waste management, steps should be taken to process and reuse panel waste from the production of technical door leaves. Producers of wood-based panels must use careful sorting methods to produce the uncontaminated wood raw material. There is also a visible development of research in managing construction and demolition waste, including waste plywood, particleboard, wood, and MDF boards (Yuan and Shen, 2011). When assessing the re-use of these materials, their mechanical and hygienic properties should be considered. This is necessary because of the formaldehyde-based adhesive resins, plastics, laminates, and films they contain.

Considering the above aspects, the aim of this study was to determine the physical and hygienic properties of particles obtained from the grinding of residues from the production of technical door leaves as a potential raw material for the production of three-layer particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Preparation of raw material
2.1. Priprema sirovine

Elements of wood-based panels, which are the residues from the production of technical door leaves of the PORTA KMI Poland S.A. company, were used for the tests. These materials are a waste product resulting from milling openings in various types of door leaves in the TechnoPORTA line - an intelligent, customized technological line for the automated production of technical doors (Figure 1).

The obtained waste of wood composite materials included: particleboard, HDF with CPL (Continuous Pressed Laminates) and finish foil, MDF, glued wood, and paper. The waste was divided into two groups. The first includes softwood, hardwood, particleboard, tubular particleboard and HDF, and the second includes insulation fiberboard, MDF, and paper honeycomb boards (Figure 2).

The materials were shredded in a cutting mill by Condux (Mankato, United States). The obtained particles were divided into fractions on a vibrating sorter by Allgaier (Uhingen, Germany) equipped with four sieves with the mesh size: 8.0, 2.0, 1.0 and 0.5 mm. The fractions from group 1 from 2.0 mm sieves - particles for the core layers (PCL) and 1.0 mm - microparticles (MP) were considered usable based on a preliminary optical assessment of their shape and dimensions. They were subjected to further tests (Figure 3).

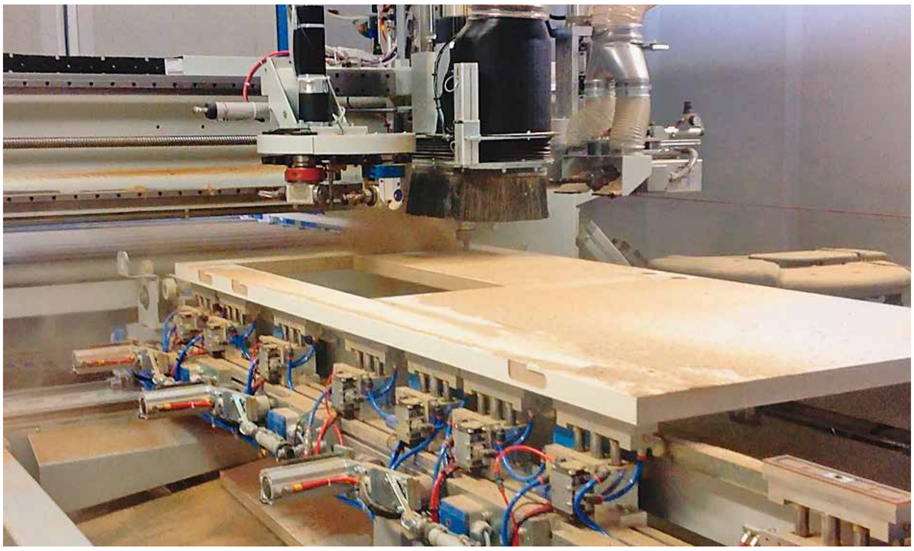

Figure 1 Milling holes in door leaves on TechnoPORTA line
Slika 1. Izrada otvora u vratnim krilima na TechnoPORTA obradnoj liniji

a)

b)

Figure 2 Waste groups a) group 1, b) group 2
Slika 2. Skupine otpadnog materijala: a) skupina 1, b) skupina 2

a) b)

Figure 3 A particle fraction considered as useful a) particles for core layers (PCL) from 2 mm sieve, b) microparticles (MP) from 1 mm sieve
Slika 3. Frakcije iverja procijenjene kao odgovarajuće: a) iverje za središnje slojeve iverica (PCL), zadržano na situ otvora oka od 2 mm, b) mikroiverje (MP), zaostalo na situ približnog otvora 1 mm

2.2 Determination of poured bulk density and dimensional analysis
2.2. Određivanje nasipne gustoće i analiza dimenzija iverja

For the fraction from the 2.0 mm sieve, the fractional composition of the grain mixture was determined. Tests were carried out on a Fritsch AS 200 tap laboratory vibrating screen (Germany) with the following sets of square mesh flat screens with perforation: 4.0, 2.0, 1.0, 0.50, 0.25, and <0.25 mm. Subsequently, a detailed dimensional analysis was also carried out, in which approximately 200 particles were used, corresponding to twice the percentage of each sieve. The length, width, and thickness of the particles were determined, based on which the essential shape factors were determined, i.e., degree of slenderness (**λ**), degree of flatness (**ψ**), width factor (m), according to the following Eqs:

$$\lambda = \frac{l}{h} \tag{1}$$

$$\psi = \frac{w}{h} \tag{2}$$

$$m = \frac{l}{w} \tag{3}$$

Where:
l – mean length of particles (mm), h – mean thickness of particles (mm), w – mean width of particles (mm)

For these fractions, the poured bulk density (**ρ**) was also determined in Eq. 4:

$$\rho = \frac{m_c - m_n}{V} \tag{4}$$

Where:
m_c –weight of measuring vessel with raw material (kg), m_n –weight of measuring vessel (kg), V – capacity of measuring vessel (m^3)

2.3 Determination of formaldehyde content
2.3. Određivanje sadržaja formaldehida

The formaldehyde content in the particles of production residues and softwood was determined by the perforator method according to EN ISO 12460-5: 2016-02. The formaldehyde content was expressed in mg formaldehyde/100 g of oven-dry sample and was calculated according to the following Eq:

$$\text{perforator value} = \frac{(A_s - A_b)\cdot f \cdot (100 + H)\cdot V}{m_H} \tag{5}$$

Where:
A_S – absorbance of analyzed extraction solution, A_b - absorbance of analysis with distilled or demineralized water, f – slope of standard curve (mg/ml), H – moisture content of particles as a mass fraction (%), m_H – mass of test pieces (g), V – volume of volumetric flask (ml).

The perforator value was calculated based on a moisture content of 6.5 %.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Characteristics of raw material
3.1. Svojstva sirovine

About 170 kg of waste from the production of technical door leaves were used for the tests, of which about 30 kg of wood was obtained as a result of cutting on a cutting mill about 153 kg of particles of all fractions of 8.0, 2.0, 1.0 and 0.5 mm (Table 1).

From group 1 of raw materials, it was possible to obtain approx. 13.6 kg of particles remaining on the 2 mm sieve, classified as particles for the core layers (PCL) and 14.2 kg of fine chips, i.e., from the 1 mm sieve - micropar-

Table 1 Amounts of particles by fraction obtained by cutting
Tablica 1. Količine iverja prema frakcijama određene prosijavanjem iz smjese dobivene glodanjem

Screen sieves, mm *Otvor oka sita*, mm	**Weight, kg** *Masa*, kg	**Fraction content in total mixture of particles, %** *Udio frakcije u ukupnoj smjesi iverja*, %
8.0	20.1	13.1
2.0	53.2	34.7
	in it 13.6	8.9
1.0	26.1	17.0
	in it 14.2	9.3
0.5	20.7	13.5
<0.5	33.0	21.6

ticles (MP). This means that out of approx. 170 kg of randomly collected production waste, characterized by a high level of differentiation, approx. 18 % of particles can be used to produce particleboards in appropriate proportions to the core layer and surfaces layers.

3.2 Poured bulk density and dimensional analysis
3.2. Nasipna gustoća i analiza dimenzija iverja

The efficiency of particleboards depends on the density of the raw material; therefore, the amount of particles required to achieve the assumed density of particleboards decreases with the increase in the density of the particles themselves (Abdul Halip *et al.*, 2022; Eisenbies *et al.*, 2019). The bulk density of particles was determined for the fractions recognized as usable. The bulk density of particles constituting a heterogeneous mixture of particles is subject to a considerable error. It largely depends on the shape and size of the particles and how they are formed in the mass and 8 % moisture. The industrial waste chips used for the tests had a moisture content of approx. 8 %. At this humidity, the bulk density of PCL is 110 kg/m^3, and the MP is 170 kg/m^3. For comparison, the bulk density of standard pine shavings is 120 kg/m^3, while industrial shavings are approx. 135 kg/m^3. Dukarska *et al.* (2021) obtained similar results in their work, proving at the same time the influence of humidity on the density of MP intended for outer layers of particleboards and PCL. On the other hand, higher values of MP were obtained for particles from construction waste and demolition wood(Azambuja *et al.*, 2018). In the case of a material such as lignocellulosic particles, the bulk density value depends primarily on the absolute density of the raw material itself. The bulk density of grain species is significantly lower than that of tree species. For triticale straw, it is approx. 30 kg/m^3, and for rapeseed straw approx. 45 kg/m^3 (Dukarska *et al.*, 2021).

Then, for PCL, the determination of the fractional composition was performed (Figure 4), and the essential shape factors were determined (Table 2).

The analysis shows that the most significant mass share is constituted by the particles retained on the

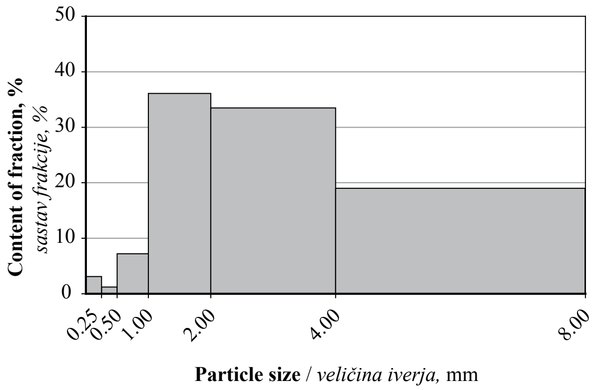

Figure 4 Fractional composition of production waste particles
Slika 4. Frakcijski sastav smjese iverja iz otpadnog materijala nastalog u proizvodnji vrata

sieves with a 2.0 and 1.0 mm mesh size. Their share is respectively 33.5 and 36.1 % of the total mixture of particles. The proportion of particles from the sieve with the largest mesh size of 4.0 mm is 19 %. A small share, less than 10 %, was observed for the fraction on the 0.5 mm sieve, while smaller particles totaled 4.3 %, which is a small share positively influencing the sizing of particles. The share of individual fractions presented in this way proves the homogeneity of the material.

The dimensional analysis is carried out for mixtures with different particle sizes, which differ in shape despite being in the same screen fraction. Knowledge of particle geometry is an important aspect to use for the production of panels, and it gives information about the homogeneity of the material, which affects the quality of the manufactured products (Dukarska *et al.*, 2021). It is also essential because of the possibility of planning and adjusting the production process. Longer particles can provide greater bending strength of the boards. The analysis of average values shows that most particles are much longer than more comprehensive. However, as confirmed by statistical analysis, in the case of particles of the 4.0 mm fraction, they do not resemble standard wood particles due to the low value of the width factor. It is a mixture in which there are many particles of considerable width but not of a small thickness. They are essentially the remains of HDF boards with CPL and

Table 2 Linear PCL dimensions and their characteristic shape factors
Tablica 2. Dimenzije iverja za središnje slojeve iverica (PCL) i njihovi karakteristični faktori oblika

Fraction, mm *Frakcija*, mm	**Average dimensions, mm** *Prosječne dimenzije*, mm			**Shape factors** *Faktori oblika*		
	l	*w*	*h*	*λ*	*ψ*	*m*
4.0	17.20±7.56	6.81±2.35	0.76±0.24	22.63	8.96	2.53
2.0	12.01±7.96	3.22±1.04	0.51±0.23	23.55	6.31	3.73
1.0	11.29±5.17	1.64±0.41	0.60±0.29	18.82	2.73	6.88
0.5	7.23±3.11	0.99±0.46	0.45±0.15	16.07	2.20	7.30

finish foil. Coefficients characterizing the particles on the sieves of 1.0 and 0.5 mm indicate slender and coarser particles. The presence of residual glue on the surface of the particles can affect the width and thickness of the particles and thus the degree of flatness. Considering the standard deviation, the particles obtained from particleboards, and timber from wood waste from construction and demolition, have similar average dimensions (Azambuja *et al*., 2018). Moreover, the dimensions of particles from recycled pallets selected for the core layer of particleboard were from 0.25 to 4.0 mm, and for the surface layers from 0.125 to 1.0 mm (Iždinský *et al*., 2021). In terms of the production of particleboards, the use of both long and smaller particles is useful because of the excellent compression of the particles and possibility of filling the gaps between them, and consequently obtaining boards of a quality that meets the requirements of the standards.

3.3 Formaldehyde content
3.3. Sadržaj formaldehida

For the production of particleboards, urea-formaldehyde and melamine-urea-formaldehyde resins are the primary source of formaldehyde (Cao *et al*., 2022; Osman *et al*., 2020). Although formaldehyde is a component of many products used daily, it is tolerated by the human body in small amounts. Due to its harmfulness, it is a carcinogenic compound, and its allowed quantity must be controlled (Pizzi *et al*., 2020).

For particle boards, the permissible formaldehyde content in boards, according to the EN 312: 2010 standard concerning the technical requirements of particle boards for the E1 hygiene class, is ≤8 mg/100 g oven-dry board. The methods for testing the emission and formaldehyde content are standardized according to EN 717-1 and EN ISO 12460-5: 2015. Due to the correlation between the emission and formaldehyde content, producers who want to expand their sales markets to buyers from outside Europe are often obliged to meet more restrictive internal requirements of individual institutions. When determining the suitability of particles derived from the processing of wood-based panel residues, the formaldehyde content of the particles should be defined, bearing in mind that the use of amino resins may increase the formaldehyde content of the panels made of them. PCL and MP were analyzed (Table 3).

There was no significant difference between the formaldehyde content in either of the tested fractions. This value is respectively 3.3 and 3.1 mg/100 g oven-dry samples. At the actual humidity of the samples at the time of testing, the expanded uncertainty of the results was at the confidence level of 0.95 is ± 0.35 for PCL and ± 0.32 for MP. For comparison, the formaldehyde content in the softwood particles is 0.8mg / 100 g oven-dry sample. The lower hygiene of waste particles is understandable. It results from the fact that these particles come from wood-based materials, for the production of which formaldehyde resins have already been used. Nevertheless, in terms of hygiene, particles from production residues can be used as a raw material for particleboard production. However, the selection and amount of binder should be considered, and the level of formaldehyde content and emission from the finished product should be controlled.

4 CONCLUSIONS
4. ZAKLJUČAK

A significant amount of production waste from the production of technical door leaves causes an expensive problem with its management. Composite ma-

Table 3 Formaldehyde content (perforator value)
Tablica 3. Sadržaj formaldehida (perforatorska vrijednost)

Tested material *Ispitivani materijal*	**Perforator value (mg/100g oven-dry sample) (calculated perforator value at a moisture content of 6.5 %)** *Perforatorska vrijednost* (mg/*100* g *apsolutno suhog drva*) (*vrijednost izračunana za sadržaj vode od 6,5 %*)
Particles for core layers (PCL) *iverje za središnje slojeve ploča iverica (PCL)*	3.3
Microparticles (MP) / *mikroiverje (MP)*	3.1

terials used in the production plant consist of wood materials, which can be an alternative source of raw material for wood to produce particleboards. In order to determine this suitability, the physical and hygienic properties of particles obtained from the comminution of the lignocellulosic composites used were determined. Based on the conducted research, it was found that the particles obtained from fragmented materials containing softwood, hardwood, particleboard, tubular particleboard with HDF are in terms of dimensions similar to the particles used in the production of boards. The formaldehyde content turned out to be higher than that of wood particles, but with an appropriate selection of the amount and type of binder, they can be reused. Separated from many fractions and materials, PCL and MP represent a potential for use as a raw material for producing three-layer particleboards.

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Corresponding address:

MARTA PĘDZIK
Łukasiewicz Research Network – Poznań Institute of Technology, Centre of Wood Technology, Winiarska St. 1, 60-654 Poznań, POLAND, e-mail: marta.pedzik@pit.lukasiewicz.gov.pl