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Development of Innovative Particleboard Panels

Razvoj inovativnih ploča iverica

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ABSTRACT • *One aim of a joint European project called DIPP (Development of Innovative Particleboard (chipboard) Panels for a better mechanical performance and a lower environmental impact) is the development of lightweight particleboards made from annual/perennial farm plants such as hemp, sunflower, topinambur, maize and miscanthus. These lightweight particleboards are intended as a possible substitution for traditional wood-based particleboards used in the furniture industry. Therefore the requirements of the EN 312 concerning the moisture-related and mechanical properties of boards for interior use have to be met.*
The results of research have shown that the internal bond strength of one-layer lightweight particleboards made in the experiment meets the requirements of EN 312 (type P2) and the internal bond strength of three-layer boards with topinambur in the core layer does not meet these requirement. The lightweight boards failed to meet the requirements of modulus of elasticity and bending strength.

Key words: *lightweight particleboards, annual/perennial farm plants, wood chips, binder, mechanical and moisture related properties*

SAŽETAK • *Jedan od ciljeva zajedničkoga europskog projekta nazvanog DIPP (Razvoj inovativnih ploča iverica s boljim mehaničkim svojstvima i manjim utjecajem na onečišćenje okoliša) jest razvoj laganih ploča iverica izrađenih od poljoprivrednih jednogodišnjih/višegodišnjih biljaka kao što su konoplja, suncokret, čičoka, kukuruz i američka trava. Takve lagane ploče iverice moguća su zamjena za tradicionalne ploče iverice izrađene od drvnog iverja, koje se danas uglavnom upotrebljavaju za proizvodnju namještaja. Prema tome, te bi ploče trebale ispunjavati zahtjeve europske norme EN 312 vezane za vodootpornost i mehanička svojstva ploča koje se upotrebljavaju u unutrašnjim prostorima.*
Rezultati provedenih istraživanja pokazali su da unutarnja čvrstoća vezanja eksperimentalno izrađenih laganih jednoslojnih ploča od jednogodišnjih/višegodišnjih biljaka ispunjava zahjeve postavljene normom EN 312 a unutarnja čvrstoća vezanja troslojnih ploča ne zadovojava normom postavljene zahtjeve. Eksperimentalne lagane ploče nisu ispunile zahtjeve norme vezane za modul elastičnosti i savojnu čvrstoću.

Ključne riječi: *lagane ploče iverice, jednogodišnje/višegodišnje poljoprivredne biljke, drvno iverje, vezivno sredstvo, mehanička svojstva i vodootpornost ploča*

1 INTRODUCTION
1. UVOD

In some European, especially South-European countries, the available wood quantity for the production of particleboards is extremely low (EPF 2005). The increased market demand in log wood of pulp and paper industries as well as the increasing use of wood pellet industry leads to high costs and shortage in the supply of wood-working and processing companies. To ensure a sufficient amount of raw material in the wood-based panel industry, mobilisation of wood from fo-

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rests which was sparse or not used in the past, used wood as well as annual and perennial plants offer alternatives for this purpose.

Up to now, materials from annual or perennial plants have substituted only small amounts of the raw material use in Europe. The suitability of agricultural raw materials for the wood-based panel industry has already been investigated earlier and published in different publications (; Rowell *et al*, 1996; BioComposites Centre, 1998; Dziurka *et al*, 2005; Dukarska *et al*, 2006).

A joint project funded by the European Commission considers the production of lightweight particleboards for the furniture industry with different densities, different raw materials of low density based on residues of agriculture, particles prepared by different techniques and different types of binders (e.g. conventional binders and binders based on tannin or acrylic resins).

The used raw materials and densities of wood-based panels are a substantial influential factor with regard to the mechanical properties of the boards. Figure 1 shows the general trend between raw density and bending strength of traditional particleboards made from wood particles. According to the latest technology, boards lighter in weight, even if made from low density wood at a raw density in the range of 450 kg/m³, are not appropriate, because such boards do not meet the requirements of particleboards according to European standards. Furthermore, lightweight particleboards with surfaces and edges of high porosity can cause problems with coating and inserting of screws and fittings.

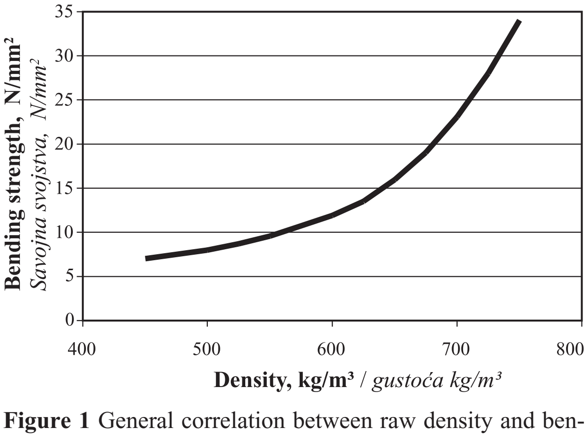

Figure 1 General correlation between raw density and bending strength of particleboards
Slika 1. Opća korelacija između gustoće sirovine i savojne čvrstoće ploča iverica

The aim of the presented work was to produce lightweight particleboards from annual/perennial farm plants such as hemp, sunflower, topinambur, maize and miscanthus and to investigate and compare mechanical and moisture related properties of these particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Light particles of different agricultural plants seem to be suitable for the production of lightweight particleboards. Therefore, the following residues (Table 1) of annual and perennial plants were used as raw material for the board production:

Hemp shives (Figure 2) show a cubical and chip-like geometry while kenaf shives show fine and small chips. The raw density of hemp shives is notably low, because the shives contain a high portion of light parenchyma.

For board production, the stalks of sunflower, maize, topinambur and miscanthus have been cut with a drum chipper and further milled with a hammer mill. The particles were fractionated, not fractionated or separated (bark and pith particles) by wind sifting and then used for the particleboard production.

3 RESULTS
3. REZULTATI

3.1 One-layer particleboards made from different annual and perennial plants (ρ = 400 kg/m³)
3.1. Jednoslojne ploče iverice proizvedene od različitih jednogodišnjih i višegodišnjih biljaka (ρ = 400 kg/m³)

One-layer boards were produced from hemp shives and stalks of sunflower, topinambur ("Jerusalem artichoke"), maize and miscanthus. These boards (see Table 2) with 16 mm thickness and a raw density of 400 kg/m³ were produced using PMDI as binder (6 % solid resin based on dry raw material).

The particleboards were manufactured without a hydrophobing agent. Particleboards made from spruce and poplar wood served as reference boards. The results of the mechanical and moisture related properties are shown in Table 2.

The lightweight boards possess the following mechanical and moisture related properties:

Figure 2 Hemp shives (left), kenaf shives (center) and topinambur (right)
Slika 2. Triješće konoplje (lijevo), hibiskusa (u sredini) i čičoke (desno)

Table 1 Material used for low density particleboards
Tablica 1. Upotrijebljeni materijali za izradu ploča iverica male gustoće

Name / *Naziv*	**Botanical name** / *Botaničko ime*	**Used material** / *Upotrijebljeni materijal*
Hemp / *konoplja*	*Cannabis sativa*	Shives / *triješće*
Kenaf[1] / *hibiskus*	*Hibiscus cannabinus*	Shives / *triješće*
Sunflower[1] / *suncokret*	*Helianthus annuus*	Stalks / *stabljika*
Maize[1] / *kukuruz*	*Zea mays*	Stalks / *stabljika*
Topinambur[1] / *čičoka*	*Helianthus tuberosus*	Stalks / *stabljika*
Miscanthus[1] / *afrička trava*	*Miscanthus sinensis gigantheus*	Stalks / *stabljika*
Rape / *uljana repica*	*Brassica napus*	Straw / *slama*
Poplar[3] / *topola*	*Populus*	Particles / *iverje*
Spruce[2] / *smreka*	*Picea abies*	Particles / *iverje*
Waste wood[2] / *drvni ostaci*	-	Particles / *iverje*

[1] after knife ring flaker and cross hammer mill (without mesh) – *nakon iveranja i mljevenja (bez prosijavanja)*
[2] after knife ring flaker and cross hammer mill (mesh 6 mm x 60 mm) - *nakon iveranja i mljevenja (prosijavanje* 6 mm x 60 mm*)*
[3] after knife ring flaker – *nakon iveranja*

Table 2 Mechanical and moisture related properties of PMDI-bonded boards with a raw density of 400 kg/m³
Tablica 2. Mehanička svojstva i vodootpornost ploča gustoće 400 kg/m³ s PMDI vezivom

Raw material *Sirovina*	**Thickness swelling**[1] *Debljinsko bubrenje*[1]	**Water absorption**[1] *Upijanje vode*[1]	**Internal bond strength** *Unutarnja čvrstoća vezanja*	**Modulus of elasticity - *MOE*** *Modul elastičnosti*	**Bending strength** *Savojna čvrstoća*
	%	%	N/mm^2	N/mm^2	N/mm^2
Sunflower stalks *stabljike suncokreta*	14.9	75.4	0.34	1057	4.5
Topinambur stalks *stabljike čičoke*	9.6	58.7	0.36	561	2.4
Maize stalks *stabljike kukuruza*	10.4	97.5	0.16	1274	6.2
Miscanthus stalks *stabljike afričke trave*	6.9	64.8	0.23	1045	5.7
Hemp shives *triješće konoplje*	28.3	145.1	0.32	1221	6.3
Spruce wood *smrekovina*	7.1	31.4	0.47	1091	5.6
Poplar wood *topolovina*	6.6	36.5	0.37	1007	4.6
EN 312 type P2[2]	no requirements *nema zahtjeva*	0.35[2]	1600[2]	13.0[2]	

[1] after being soaked in water for 24 h – *nakon potapanja 24 sata u vodi*
[2] requirements of EN 312: boards for interior use (including furniture) under dry conditions (type P2) of > 13...20 mm thickness – *zahtjevi prema normi EN 312: ploče za unutrašnju upotrebu (uključujući namještaj) u suhim uvjetima (tip P2) za ploče debljine 13...20 mm*

- Boards made from stalks of sunflower and topinambur have corresponding internal bond strength to particleboards made from poplar wood. The requirement of EN 312 type P2 is met.
- The bending strength (2…6 N/mm²) of all boards is low. The boards made from hemp shives possess the highest bending strength and the boards made from topinambur stalks the lowest. The bending strengths of lightweight boards do not meet the requirement of EN 312 type P2.
- The boards made from stalks of topinambur and miscanthus have a low thickness swelling which is in the range of thickness swelling of particleboards made from wood. On the other hand the water uptake of the boards made from annual and perennial plants is higher compared to boards made from wood.

3.2 One-layer particleboards made from topinambur stalks: Influence of pith material
3.2. Utjecaj srži materijala na svojstva jednoslojne ploče iverice izrađene od stabljika čičoke

The influence of pith material (parenchyma) on particleboard properties was determined in detail on boards made from topinambur stalks. The pith material (lightweight material) and the epidermis or bark and stalk material (heavyweight material), respectively, should be separated by wind sifting with a zigzag sifter. After wind sifting, the amount of the lightweight fraction was 20 % and of the heavyweight fraction 80 %. Unfortunately, the separation of the pith material from the bark was insufficient; the separation was mainly between lightweight and heavyweight particles and not between pith and bark.

Nevertheless, one-layer particleboards of 19 mm thickness were prepared with tannin-formaldehyde resin as binder. The particles were not fractionated by sieves. The target density of particleboards was 420 kg/m³. The results of mechanical and moisture related properties of the boards are given in Table 3.

Table 3 shows the following results:

- The internal bond strength (0.36 N/mm²) of the lightweight TF-bonded board (density 420 kg/m³) meets the requirement of EN 312 (type P2). No influence of the pith material was recorded regarding the internal bond strength of the boards.
- The lightweight boards failed to meet the requirements of modulus of elasticity and bending strength.
- The board prepared from particles of the heavyweight fraction shows only a marginally higher modulus of elasticity and bending strength compared to boards made from particles before wind sifting.

3.3 Three-layer particleboards made from annual/perennial plants
3.3. Troslojna ploča iverica proizvedena od jednogodišnjih/višegodišnjih biljaka

Further investigations were focussed on miscanthus and topinambur as raw material for board production. Moreover, the bending strength as well as the modulus of elasticity should be upgraded by the produc-

Table 3 Mechanical and moisture related properties of TF-bonded particleboards
Tablica 3. Mehanička svojstva i vodootpornost ploča iverica s TF vezivom

Raw material / fraction *Sirovina / frakcija*	**Thickness swelling (24h)** *Debljinsko bubrenje (24 h)*	**Internal bond strength** *Unutarnja čvrstoća vezanja*	**Modulus of elasticity** *Modul elastičnosti*	**Bending strength** *Savojna čvrstoća*
	%	N/mm²	N/mm²	N/mm²
before wind sifting *prije prosijavanja na vjetru*	18.0	0.35	784	4.2
100 % heavyweight fraction *100 % teška frakcija*	17.5	0.36	869	4.6
90 % heavyweight fraction 10 % lightweight fraction *90 % teška frakcija* *10 % laka frakcija*	15.9	0.36	848	4.5
EN 312 type P2* EN 312 tip P2*	no requirement *bez zahtjeva*	≥ 0.35	≥ 1600	≥ 13.0

* requirements of EN 312: boards for interior use (including furniture) under dry conditions (type P2) of > 13...20 mm thickness
* *zahtjevi prema normi EN 312: ploče za unutrašnju upotrebu (uključujući namještaj) u suhim uvjetima (tip P2) za ploče debljine 13...20 mm*

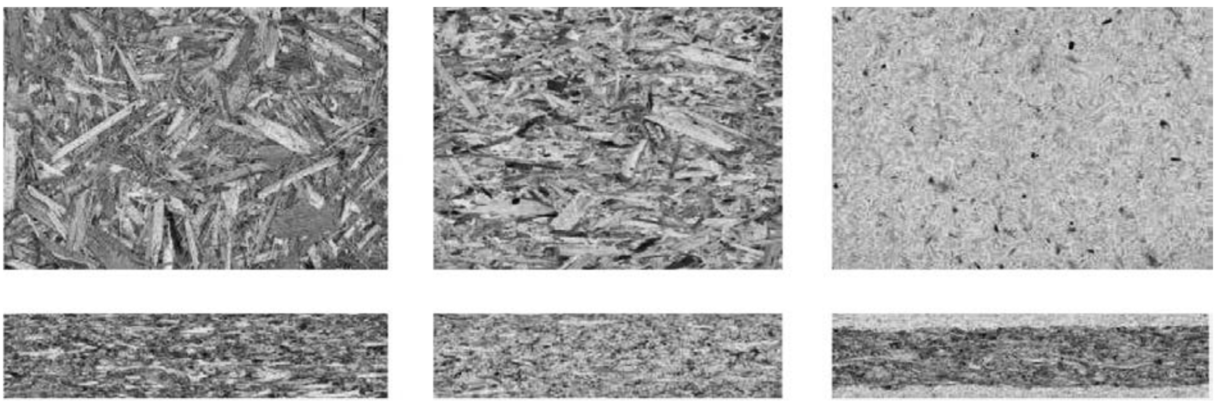

Figure 3 One-layer PMDI-bonded particleboard prepared from miscanthus stalks (left), one-layer UF-bonded particleboard prepared from topinambur stalks (center), three-layer UF-bonded particleboard prepared from miscanthus stalks (core layer) and spruce wood (surface layer) (right)
Slika 3. Jednoslojna ploča iverica izrađena od stabljika afričke trave i PMDI veziva (lijevo), jednoslojna ploča iverica izrađena od stabljika čičoke i UF veziva (u sredini), troslojna ploča iverica izrađena od stabljika afričke trave (središnji sloj) i smrekovine (površinski sloj) te UF veziva (desno)

Table 4 Mechanical and moisture related properties of one- and three-layer particleboards (SL: surface layer, CL: core layer)
Tablica 4. Mehanička svojstva i vodootpornost jednoslojnih i troslojnih ploča iverica (SL –površinski sloj, CL – središnji sloj)

Layers *Slojevi*	**Raw material** *Sirovina*	**Binder** *Vezivo*	**Density** *Gustoća*	**Thickness swelling (24 h)** *Debljinsko bubrenje (24 h)*	**Internal bond strength** *Unutarnja čvrstoća vezanja*	**Modulus of elasticity** *Modul elastičnosti*	**Bending strength** *Savojna čvrstoća*
			kg/m³	%	N/mm²	N/mm²	N/mm²
1	miscanthus *afrička trava*	UF	632	31.1	0.32	2546	13.2
1	miscanthus *afrička trava*	PMDI	644	7.2	0.49	3323	22.1
3	miscanthus (SL) *afrička trava (SL)* miscanthus (CL)	UF	647	20.7	0.26	2630	15.1
3	spruce (SL) *smrekovina (SL)* miscanthus (CL) *afrička trava (CL)*	UF	647	24.1	0.28	2874	17.9
1	topinambur *čičoka*	UF	658	31.6	0.79	2393	14.6
3	spruce (SL) *smrekovina (SL)* topinambur (CL) *čičoka (CL)*	UF (SL) TF (CL)	440	18.5	0.30	819	4.6
3	poplar (SL) *topolovina SL)* topinambur (CL) *čičoka (CL)*	UF (SL) TF (CL)	440	16.3	0.34	919	5.4
EN 312 type P2*					≥ 0.35	≥ 1600	≥ 13.0

* requirements of EN 312: boards for interior use (including furniture) under dry conditions (type P2) of > 13...20 mm thickness
* *zahtjevi prema normi EN 312: ploče za unutrašnju upotrebu (uključujući namještaj) u suhim uvjetima (tip P2) za ploče debljine 13...20 mm*

tion of three-layer particleboards. Three-layer particleboards with a density of about 650 kg/m³ and 440 kg/m³ and different binders were produced. One-layer particleboards served as reference boards. Figure 3 shows the surfaces and edges of some boards. Table 4 shows the mechanical and moisture related properties of the boards.

The results of the mechanical and moisture related properties of the boards shown in Table 4 are:

- One-layer PMDI-bonded particleboard made from miscanthus shows the best mechanical properties and the lowest thickness swelling after being soaked in water for 24 h.
- Three-layer UF-bonded particleboards made from miscanthus have a higher bonding strength and MOE if spruce wood is used for the surface layer.
- One-layer UF-bonded boards prepared from topinambur show higher internal bonding strength and a lower bending strength compared to corresponding boards from miscanthus.
- Lightweight (density 440 kg/m³) three-layer boards with topinambur in core layer do not meet the requirements of EN 312 type P2.

4 CONCLUSION
4. ZAKLJUČAK

The lightweight particleboards made from annual/perennial farm plants are intended as a possible substitution for traditional wood-based particleboards used in the furniture industry. Particles with high intra-porosity should be used for the production of lightweight boards. In this way some agricultural plants are most suitable for this purpose, because the stalks of sunflower, topinambur and maize are filled with light parenchyma cells.

The internal bond strength of one-layer lightweight particleboards made in the experiment meets the requirements of EN 312 (type P2) while the internal bond strength of three-layer boards with topinambur in the core layer does not meet these requirements. The lightweight boards failed to meet the requirements of modulus of elasticity and bending strength.

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