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Starch Impregnation Effect of Testliner Paper on Stiffness of Honeycomb Panels with Slender Cells

Učinak impregnacije testliner papira škrobom na krutost ploča sa srednjicom od papirnog saća uskih ćelija

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 2. 3. 2022.
Accepted – prihvaćeno: 3. 4. 2022.
UDK: 547.458.61; 630*86; 676.2-027.33
https://doi.org/10.5552/drvind.2022.0024

ABSTRACT • *The study aimed to determine the effect of impregnation with modified starch of recycled paper (Testliner) on elasticity constants of slender core cells and the influence on the elasticity constants and strength of honeycomb with facings made of thin particleboards. The experimental tests were carried out on beams subjected to three-point bending. It was shown that slender hexagonal cells significantly differentiate their elastic properties and elastic properties of honeycomb panels in the main directions of orthotropy. Impregnation of the Testliner paper with modified starch reduces the values of the modulus of elasticity of the cells by about 8.8 % and reduces the values of the modulus of elasticity of the honeycomb panels by at least 6.9 %. Analytical solutions that do not take into account the structural form of the core cannot be used to calculate the modulus of elasticity of sandwich panels with hexagonal core cells.*

KEYWORDS: *honeycomb; hexagonal cell; orthotropy; impregnation; elastic properties; strength*

SAŽETAK • *Cilj predstavljenog istraživanja bio je utvrditi učinak impregnacije recikliranog papira (testliner papira) modificiranim škrobom na konstante elastičnosti uskih ćelija papirne jezgre i učinak na konstante elastičnosti papirnog saća obostrano obloženoga tankim pločama ivericama. Eksperimentalna su ispitivanja provedena na uzorcima podvrgnutima savijanju u tri točke. Pokazalo se da vitke heksagonalne ćelije u glavnim smjerovima ortotropije znatno diferenciraju svoja svojstva elastičnosti, kao i svojstva elastičnosti ploča s jezgrom od papirnog saća. Impregnacija testliner papira modificiranim škrobom smanjuje vrijednosti modula elastičnosti ćelija za otprilike 8,8 %, ali i vrijednosti modula elastičnosti ploča sa srednjicom od papirnog saća za najmanje 6,9 %. Analitička rješenja kojima se ne uzima u obzir strukturni oblik jezgre ne mogu se upotrijebiti za proračun modula elastičnosti tzv. sendvič-ploča, čija jezgra ima heksagonalne ćelije.*

KLJUČNE RIJEČI: *papirno saće; heksagonalne ćelije; ortotropija; impregnacija; elastična svojstva; čvrstoća*

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1 INTRODUCTION
1. UVOD

Kraft paper, which is commonly used in the production of light wood-based honeycomb panels, is produced by chemical defibering with at least 80 % virgin fibers. It is widely used as a packaging material (Twede *et al*., 2015). Paper as such can be recycled up to six times, but it is assumed that the life cycle of cellulose fiber in Europe has an average of 3.5 times (Ghinea *et al*., 2017). As reported by European and global organizations monitoring the pulp and paper industry, in 2018, more than half of the global paper production was made of recycled paper known as Testliner. For hundreds of years, the paper industry has been using various methods of protecting paper against moisture (sizing), including impregnation. A side effect of impregnation may be a reduction in the paper strength, which was confirmed in the work of Pohl (2009). In recent years, efforts have been made to develop environmentally friendly substances that increase the hydrophobic properties of cellulose fibers. These are vegetable proteins and starch (Lagus, 2019; Ren and Li, 2005). Starch is the second most used agent in the paper industry, right after clay fillers. The usual cellulose pulp supplement is within the range of 2 % – 4 % (Maurer, 2009; Zeng, 2013). Its presence increases the mechanical resistance of the paper to tearing, improves the quality of prints, and most of all increases the resistance to moisture by filling the pores in the cellulose fiber mesh. In 2009, modified starch accounted for 66 % of the starch used for sizing (Zeng, 2013; Słonina *et al*., 2022).

Lightweight, wood-based honeycomb boards are of great use in the production of furniture (Librescu and Hause, 2000; Michanickl, 2006). However, a significant limitation of the widespread use of honeycomb boards in the furniture industry is their low stiffness and strength, compared to classic wood materials, such as particleboard, MDF board or plywood. (Shalbafan *et al*., 2012; Smardzewski, 2013; Smardzewski and Jasińska, 2016; Khojasteh-Khosro *et al*., 2020). However, these boards are distinguished by an attractive quality factor (Peliński and Smardzewski, 2020; Beckers *et al*., 2021).

Scientific research of three-point bent sandwich panels consisting of a core with hexagonal cells concerned the modeling of deflection of panels with regular hexagonal cells (Chen, 2011), facings damage, and core cell collapse (Steeves and Fleck, 2004; Crupi *et al*., 2012; Sun *et al*., 2017; Palomba *et al*., 2019; Hussain *et al*., 2019; Wang *et al*., 2019; Ma *et al*., 2021), damage to the paper core cells (Chen *et al*., 2011; Chen and Yan, 2012; Hao *et al*., 2018).

Research has also begun on protecting wood-based cellular panels against the destructive effects of variable temperature and air humidity (Bekhta *et al*., 2006; Ozarska and Harris, 2007; Nilsson *et al*., 2017; Słonina *et al*., 2022).

On the other hand, the effect of the hydrophobic impregnation of paper on the orthotropic properties of slender hexagonal core cells and their influence on the mechanical properties of the cell plates was not investigated. Therefore, the study aimed to determine the effect of impregnation with modified starch of Testliner paper on the elasticity constants of slender core cells and determine the influence of these changes on the elasticity constants and strength of honeycomb panels with facings made of thin particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Shape and properties of honeycomb cells
2.1. Oblik i svojstva ćelija papirnog saća

The method of modeling hexagonal cells has been presented in numerous scientific papers (Gibson, 2005; Peliński *et al*., 2017; Słonina *et al*., 2020; Słonina *et al*., 2022). They describe in detail the method of selecting the cell geometry and its production processes. For the purposes of this study, the shape of one slender cell was designed (Figure 1). The elongated, spindle-shaped geometry was to ensure strong orthotropic properties of the cell and the core made of paper. Table 1 lists the basic dimensions of the cell influencing its elastic properties.

The cells and cores of the honeycomb boards were made of paper Testliner-2 with a thickness of 0.15 mm and basis weight of 123 g/m^2 (Sam-Brew *et al*., 2011; Słonina *et al*., 2022). Testliner-2 paper was pro-

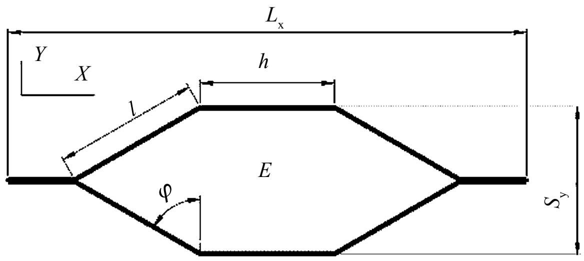

Figure 1 Slender cell model
Slika 1. Model uskih ćelija

Table 1 Geometric characteristics of test cell, where (Figure 1)
Tablica 1. Geometrijska svojstva ispitivanih ćelija: (sl. 1.)

S_y, mm	L_x, mm	l, mm	h, mm	t, mm	φ, °
13.33	46.48	13.0	12.0	0.15	60

ρ – relative density, S_y – width, L_x – length, l – free wall length, h – length of common wall, t – wall (paper) thickness, φ – angle of wall
ρ – relativna gustoća, S_y – širina, L_x – duljina, l – duljina slobodne stijenke, h – duljina kontaktne stijenke, t – debljina stijenke (papira), φ – kut stijenke

Table 2 Physical and mechanical properties of materials used
Tablica 2. Fizička i mehanička svojstva upotrijebljenih materijala

Code *Oznaka*		Thickness, mm *Debljina*, mm	*MC*, %	Density, kg/m³ *Gustoća*, kg/m³	E_i, MPa		MOE_i, MPa		υ_{ij}	
					x	*y*	*x*	*y*	*xy*	*yx*
PN	Mine	0.15	5.72	686	5707	2188	46	16	0.411	0.147
	SD	0.01	0.32	32	672	113	1.8	0.30	0.043	0.023
PS	Mine	0.16	7.05	730	5190	2642	49	20	0.308	0.109
	SD	0.02	0.41	28	374	102	3.1	0.34	0.033	0.010
PB	Mine	2.77	6.76	942	4116	3445	14	10	0.161	0.129
	SD	0.02	0.53	18	276	210	2.3	1.50	0.027	0.026

PN – paper not impregnated with starch, PS – starch-impregnated paper, PB – particleboard, (E_i – modulus of linear elasticity, MOE_i – modulus of rupture, υ_{ij} – Poissons ratio, *i, j* – appropriately *x,y* – orthotropy directions, *SD* – standard deviation) / *PN – neimpregnirani papir, PS – papir impregniran škrobom, PB – ploča iverica (E_i – modul linearne elastičnosti, MOE_i – modul loma, υ_{ij} – Poissonov omjer, i, j – prikladnost, x,y – smjerovi ortotropije, SD – standardna devijacija)*

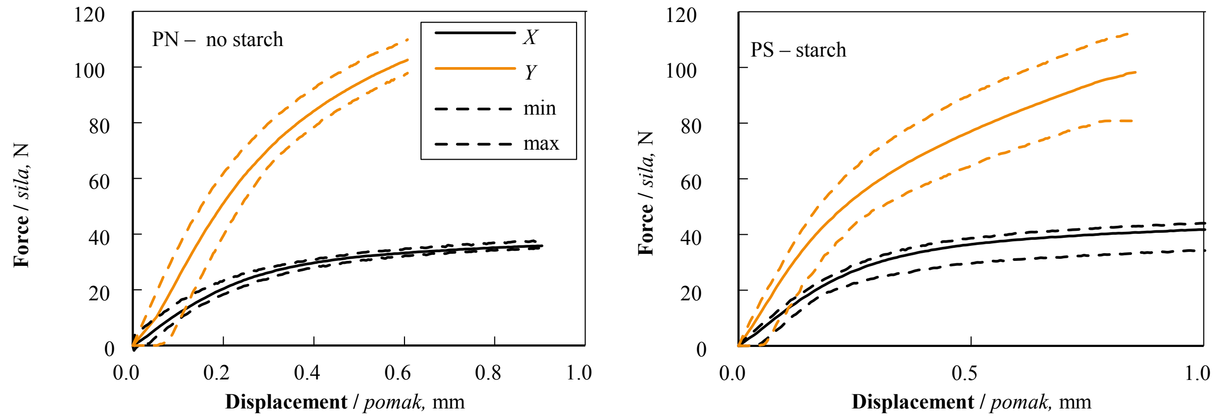

Figure 2 Relationships between force and displacement in uniaxial tensile test of non-impregnated (PN) and impregnated (PS) paper; the dotted line marks the smallest and largest force values recorded for each type of sample
Slika 2. Odnos između sile i pomaka u jednoosnom vlačnom ispitivanju neimpregniranoga (PN) i impregniranoga (PS) papira; isprekidana linija označava najmanju i najveću zabilježenu silu za svaku vrstu uzorka

duced in the company HM Technology (HM Technology, Brzozowo, Poland). For cell formation, non-impregnated (PN) and impregnated (PS) papers were prepared with a 10 % aqueous solution of modified starch (patent number P.430486). The paper (Słonina *et al.*, 2020) presents in detail the method of paper impregnation, the method of forming cells, and obtaining cores. The elastic properties of the paper were determined in accordance with the standard (ISO 1924-2, 2008) and are presented in Table 2. The elastic properties of thin particleboard (PB) with a thickness of 3 mm, used to make the facings of the honeycomb boards, are also given (Egger, Rion-des-Landes, Francja). These properties were determined in accordance with the standard (ISO 13061-6, 2014). The uniaxial tensile characteristics of the papers and particleboard are shown in Figure 2 and 3.

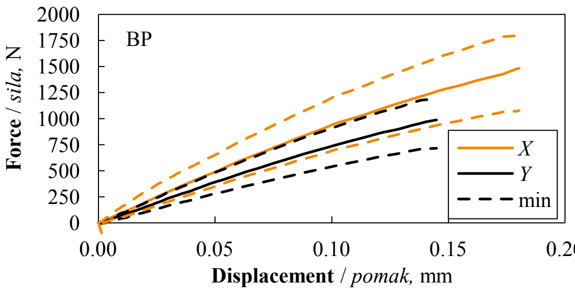

Figure 3 Relationships between force and displacement in uniaxial tensile test of particleboard (PB); the dotted line marks the smallest and largest force values recorded for each type of sample
Slika 3. Odnos između sile i pomaka u jednoosnom vlačnom ispitivanju ploče iverice; isprekidana linija označava najmanju i najveću zabilježenu silu za svaku vrstu uzorka

Based on Figure 2 and the data in Table 2, it can be seen that the stiffness and strength of the paper in the machine direction (MD=*x*) is significantly higher compared to the properties in the cross-machine direction (CD=*y*). Material tests have also shown that impregnation of the paper with starch slightly reduces the modulus of elasticity in the (*x*) direction but increases its value in the (*y*) direction and slightly increases the tear strength of the paper. Therefore, it was decided to form the cells in further studies in such a way to make their orthotropy direction (*x*) (Figure 1) consistent with the cross direction (*y*) of the paper. Figure 3 also shows that thin particleboards are characterized by strong orthotropy. Thus, it was decided that the direction of the orthotropy of the plate (x) should always coincide with the direction of the longer side of the cellular plate sample.

The cell relative density ρ was calculated from the following Eq. (Peliński *et al.*, 2017):

$$\rho = 1 - \frac{F_s}{F^*} \tag{1}$$

Where: F_s and F^* the surface of the substance and the surface of the cell, respectively,

$$F^* = L_x \cdot S_y \tag{2}$$

$$S_y = 2 \cdot (l \cdot \cos(\varphi) + t) \tag{3}$$

$$L_x = 2 \cdot \left(\frac{h}{2} + l \cdot \sin(\varphi) + \frac{h}{2} - t \cdot \cot(\varepsilon) \right) \tag{4}$$

$$F^* = 4 \cdot (l \cdot \cos(\varphi) + t)(h + l \cdot \sin(\varphi) - t \cdot \cot(\varepsilon)) \tag{5}$$

$$F_s = F^* - F_1 - F_2 - F_3 \tag{6}$$

$$F_1 = 2 \cdot l \cdot \cos(\varphi) \cdot (h - 2 \cdot t \cdot \cot(\varepsilon) + l \cdot \sin(\varphi)) \tag{7}$$

$$F_2 = 2 \cdot ((l \cdot \cos(\varphi) + t) - 2 \cdot t)(h - 2 \cdot t \cdot \cot(\varepsilon)) \tag{8}$$

$$F_3 = 2 \cdot l \cdot \sin(\varphi) \cdot \cos(\varphi) \cdot (l - t \cdot \cot(\varepsilon)) \tag{9}$$

Since it was assumed that hexagonal honeycomb cells are characterized by strong orthotropy resulting from their slender geometry, two longitudinal elasticity modules E_x^c, E_y^c, two Poisson's coefficients ϑ_{xy}^c, ϑ_{yx}^c, were calculated for a single cell, and Kirchhoff's module G_{xy}^c,

$$E_x^c = \frac{E_x \cdot t^3 \cdot \left(\frac{h}{l} + \sin(\varphi) \right)}{l^3 \cdot \cos^3(\varphi)} \tag{10}$$

$$E_y^c = \frac{E_x \cdot t^3 \cdot \cos(\varphi)}{l^3 \cdot \left(\frac{h}{l} + \sin(\varphi) \right) \cdot \sin^2(\varphi)} \tag{11}$$

$$G_{xy}^c = E_x \cdot \left(\frac{t}{l} \right)^3 \cdot \frac{\frac{h}{l} + \sin(\varphi)}{\left(\frac{h}{l} \right)^2 \cdot \left(1 + \frac{2 \cdot h}{l} \right) \cdot cos(\varphi)} \tag{12}$$

$$\vartheta_{xy}^c = \frac{\sin(\varphi) \cdot \left(\frac{h}{l} + \sin(\varphi) \right)}{\cos^2(\varphi)} \tag{13}$$

$$\vartheta_{yx}^c = \frac{\cos^2(\varphi)}{\left(\frac{h}{l} + \sin(\varphi) \right) \cdot \sin(\varphi)} \tag{14}$$

Table 3 presents the calculation results of the elastic properties of the core cells. It shows that the relative density of cells is constant and equal to 0.0785. In addition, the cell shows strong orthotropy; therefore, it will significantly affect the elastic properties of the modeled honeycomb panels. The influence of the impregnation with starch on Testliner paper on the elastic properties of the cells also seems to be significant. Impregnation reduces the values of the linear elasticity modulus by the Kirchhoff modulus. However, it does not change the value of the Poisson's coefficients, as these depend only on the cell geometry. With this in mind, samples of honeycomb panels with the longitudinal and transverse arrangement of the core cells were prepared for further research.

2.2 Honeycomb manufacturing and testing
2.2. Proizvodnja i ispitivanje ploče sa srednjicom od papirnog saća

On non-decorative particleboard surfaces, glue PVAc Woodmax FF12.47 class D2 delivered by Synthos Adhesives (Oświęcim, Poland) was applied in the amount of approximately 110 g/m^2. Then, a particleboard frame with a thickness of 16.1 mm was placed along the edges of one of the facing, and an expanded paper core with a thickness of 16.3 mm was inserted inside it. Care was taken that the longitudinal axis of the cell (x) was consistent with or perpendicular to the axis (x) of the particleboard. The assembly was closed with another particleboard to form a panel with a honeycomb core. The gluing process of the set took place in a hydraulic press Orma Macchine NPC/DIGIT 6/90 25x13 (Bergamo, Italy) for 25 minutes at a pressure of 0.7 MPa. For each type of impregnated and non-impregnated paper, six 22 mm thick panels were made. The panels were seasoned in laboratory conditions until a constant mass of samples was obtained, which proved that they maintained the hygroscopic equilibrium. After this time, the boards were cut into beams w=50 mm wide and 20 times their thickness plus 50 mm long. The beam samples were splitted in such a way as to obtain the longitudinal and transverse arrangement of the core cells (Fig. 4). For each type of

Table 3 Physical and mechanical properties of non-impregnated and starch-impregnated cells
Tablica 3. Fizička i mehanička svojstva ćelija neimpregniranog papira i papira impregniranog škrobom

Code *Oznaka*	ρ	E_i^c, **MPa**		G_{ij}^c, **MPa**	ϑ_{ij}^c	
		x	*y*	*xy*	*xy*	*yx*
N	0.0785	0.1255	0.0033	0.0129	6.1976	0.1614
S		0.1141	0.0030	0.0118		

E_i^c– modulus of linear elasticity, ϑ_{ij}^c - Poisson's ratio, G_{ij}^c – Kirchhoff moduli, *i, j* – x, y, respectively - orthotropy directions) / E_i^c – *modul linearne elastičnosti,* ϑ_{ij}^c *– Poissonov omjer,* G_{ij}^c *– Kirchhoffovi moduli, i, j – x, y pravci ortotropije)*

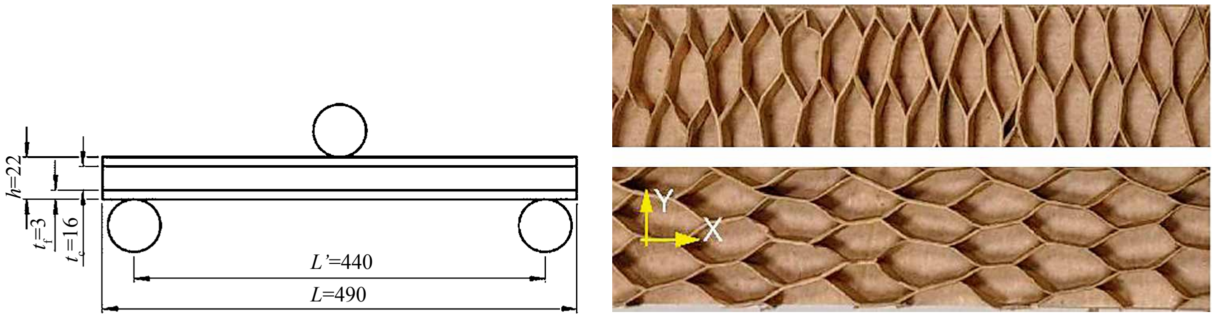

Figure 4 Honeycomb boards samples
Slika 4. Uzorci ploča sa srednjicom od papirnog saća

core and impregnation, 10 samples were made, a total of 40 pieces.

The beams were subjected to a three-point bending (Fig. 4) according to the standard (EN 310, 1993) on a Zwick Z100 testing machine (Zwick GmbH, Ulm, Germany). During the tests, the value of the force was recorded with an accuracy of 2 N and the deflection of the beams in the direction of acting force with an accuracy of 0.01 mm. Then, for the test samples, based on the measured values of the maximum forces F_{max} (N), modulus of rupture $MOR_{p(x,y)}$ (MPa) was calculated for each direction of orthotropy (x, y) from Eq. 15:

$$MOR_{p}=\frac{3\cdot F_{max}\cdot L'^{3}}{2\cdot w\cdot h^{3}} \qquad (15)$$

Where: F_{max} is the force at the fracture point (N), L' = 20 h is the length of the support span (mm), h is the thickness of the beam (mm), w is the width of the beam (mm). On the other hand, the linear elasticity modulus was calculated based on the relationship of force and deflection in the linear range $E_{p(x,y)}$ (MPa) for each direction of orthotropy (x, y) from Eq. 16:

$$E_{p(x,y)}=\frac{(0.4\cdot F_{max}-0.1\cdot F_{max})\cdot L'^{3}}{48\cdot(f_{0.4Fmax}-f_{0.1Fmax})\cdot I_{s}} \qquad (16)$$

Where: $f_{0.4Fmax}$ is the deflection of the beam in mm for a load equal to $0.4\cdot F_{max}$, $0.1\cdot F_{max}$ (N), $I_{s}=\frac{w\cdot h^{3}}{12}$ is the crosssection moment of inertia (mm^4).

Bodig and Jayne (Bodig and Jayne, 1982) developed simplified equations for layered wood-based panels consisting of three orthotropic layers with symmetric facings. The equations developed by Bodig and Jayne may be used to calculate the stiffness of the sandwich panel if we assume each layer as a continuum. Of course, these equations are unable to account for cell geometry effect. Nevertheless (Chen and Yan, 2012), we tried to compare our simulated results with the estimates from Eqs. 17, 18 and 19:

$$E_{Px}=\frac{2\cdot E_{x}^{f}\cdot t^{f}+E_{x}^{c}\cdot t^{c}}{h} \qquad (17)$$

$$E_{Py}=\frac{2\cdot E_{x}^{f}\cdot t^{f}+E_{y}^{c}\cdot t^{c}}{h} \qquad (18)$$

$$G_{Pxy}=\frac{2\cdot G_{xy}^{f}\cdot t^{f}+G_{xy}^{c}\cdot t^{c}}{h} \qquad (19)$$

Where: E_{x}^{f} – linear elastic modulus of the facing (PB), E_{x}^{c}, E_{y}^{c} – core elasticity modulus in x, y direction, G_{xy}^{f}, G_{xy}^{c} - Kirchhoff module of facing and core, t^f, t^c – facing thickness and core thickness. The data for the calculations are summarized in Tables 2 and 3. In the case of particleboards, their Kirchhoff modulus was calculated in accordance with (Bodig and Jayne, 1982) and is equal G_{xy}^{f} =1774 MPa.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 5 shows the method of deformation of beams subjected to three-point bending, and Figure 6 shows the relationship of force to deflection.

Figure 6 shows that the individual sample populations were characterized by high homogeneity, especially in terms of deflections corresponding to the linear elasticity of beams. Comparing the curves for the mean values, it can be seen that the maximum value of

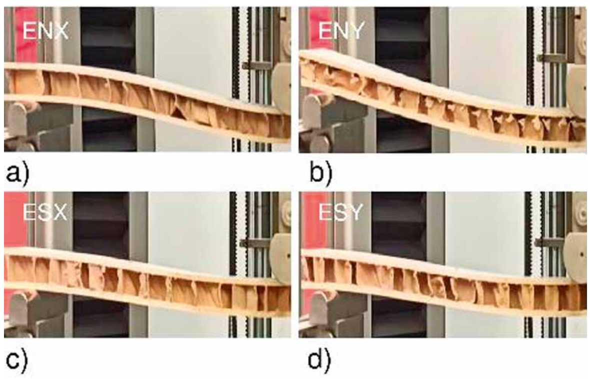

Figure 5 Method of deformation of beams subjected to three-point bending: a, b) non-impregnated paper; c, d) impregnated paper; a, c) orthotropy direction x; b, d) orthotropy direction y
Slika 5. Načini deformacije ispitnih uzoraka (greda) podvrgnutih savijanju u tri točke: a), b) obično legende idu ispod tablice (i u engl. tekstu)neimpregnirani papir; c), d) impregnirani papir; a), c) smjer ortotropije x; b), d) smjer ortotropije y

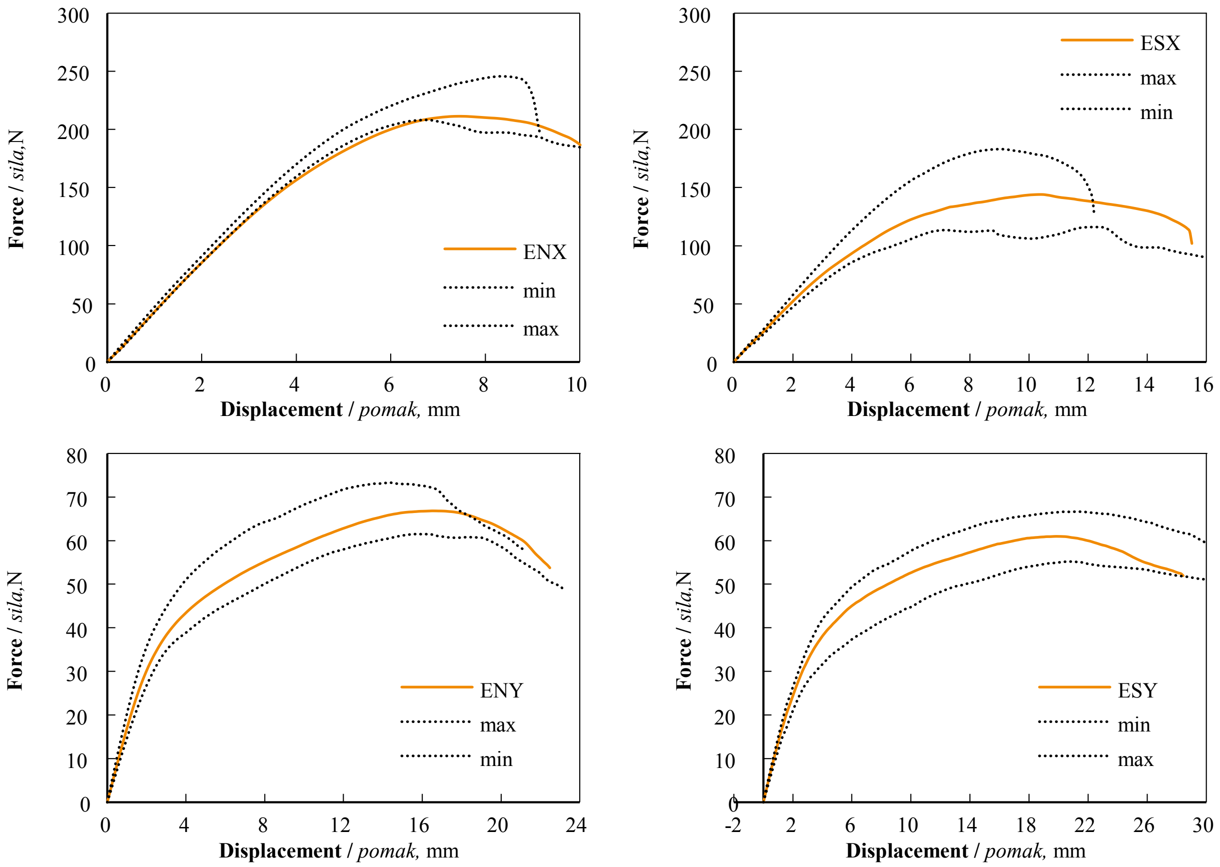

Figure 6 Dependence of force on a deflection for beams subjected to bending: ENX, ENY – beams with non-impregnated paper and cells oriented in *x* and *y* direction, ESX, ESY – beams with impregnated paper, and cells oriented in *x* and *y* direction; the dotted line marks the smallest and largest force values recorded for each type of sample

Slika 6. Ovisnost sile o pomaku za grede podvrgnute savijanju: ENX, ENY – grede od neimpregniranog papira s ćelijama orijentiranima u smjeru *x* i *y*, ESX, ESY – grede od impregniranog papira s ćelijama orijentiranima u smjeru *x* i *y*; isprekidana linija označava najmanju i najveću zabilježenu silu za svaku vrstu uzorka

the force causing bending F_{max}=211 N occurs for beams ENX (with non-impregnated cells and for the direction of orthotropy (x)). The impregnation of the paper with starch, for the identical arrangement of cells (ESX), causes the value of the maximum destructive force to decrease to 144 N. The values of average destructive forces for the direction of orthotropy (y) are in a similar proportion. The maximum value of the force causing bending of ENY beams (with non-impregnated cells and for the orthotropy direction (y)) is equal to F_{max}=67 N. The starch impregnation of the paper reduces the maximum destructive force to 61 N. It follows that the stiffness of the beams in the (y) direction is less sensitive to the impregnation of the paper than in the (x) direction. Table 4 shows, however, that the slender cell of the paper core has a significant influence on the orthotropic properties of the honeycomb panel. The modulus of elasticity in the (x) axis is greater than the modulus of elasticity in the (y) axis by 61.5 % and 55.5 % for non-impregnated and impregnated cores, respectively. At the same time, the impact of impregnation of Testliner paper with modified starch on the values of these modules for selected directions of orthotropy of the boards was noticeable. For the (x) direction, the impregnation of the paper caused a reduction in value F_{Px} of 19.3 % and for direction (y) of 6.9 %. It is worth noting that this change was caused only by the change in the value of the linear elasticity modulus of the core cells from E_x^c=0.125 MPa to 0.114 MPa, and from E_y^c =0.033 MPa to 0.030 MPa. In this case, the differences are 8.8 % and 9.1 %, respectively, in favor of cells not impregnated with starch. The analytical calculations made with the use of equations 17, 18, 19 do not show, however, such a significant influence of the linear elasticity modulus of the core on the modulus of elasticity of the cellular sheet (Table 4), which is explained by the equation referred to below for Eq. 17,

$$E_{Px} = \frac{2 \cdot E_x^f \cdot t^f}{h} \cdot \left(1 + \frac{E_x^c}{2 \cdot E_x^f} \cdot \frac{t^c}{t^f}\right) \tag{20}$$

Where, after substituting the appropriate numerical values, we get:

$$\begin{aligned} E_{Px} &= 1122.54 \cdot \left(1 + 1.52 \cdot 10^{-5} \cdot 5.33\right) = \\ &= 1122.54 \cdot \left(1 + 8.1 \cdot 10^{-5}\right) \end{aligned} \tag{21}$$

It follows that the combined effect of E_x^c and t^c on E_{Px} is equal to 8.1 $\cdot 10^{-5}$, therefore negligibly small. Therefore, the solutions proposed by (Bodig and Jayne,

Table 4 Modulus of elasticity of cellular plates
Tablica 4. Modul elastičnosti ploča s jezgrom od papirnog saća heksagonalnih ćelija

Module	N		S	
	Exp	A	Exp	A
E_{Px}	1874 (104)	1123	1484 (146)	1123
E_{Py}	709 (94)	1123	660 (63)	1123
G_{Pxy}	-	484	-	484

exp - experimental results, A - analytical calculations, SD - standard deviation / *exp – eksperimentalni rezultati, A – analitičke kalkulacije, SD – standardna devijacija*

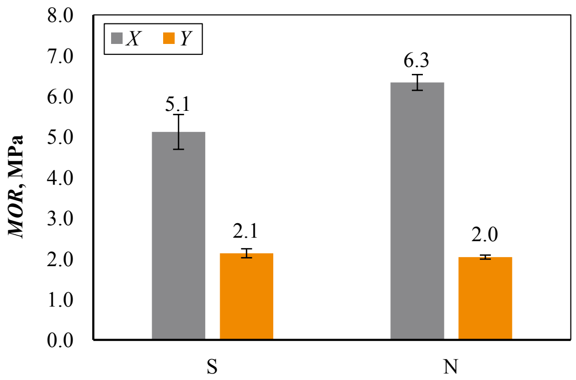

Figure 7 Bending strength of cellular plates (whiskers indicate standard deviations)
Slika 7. Čvrstoća na savijanje ploča sa srednjicom od papirnog saća heksagonalnih ćelija („viskeri" označavaju standardne devijacije)

1982; Chen and Yan, 2012) do not apply to structural cell cores.

The slender core cells also have a marked effect on the strength of the cell plates. Figure 7 shows that the bending strength in the direction of the (*x*) axis is greater than the strength in the direction of the (*y*) axis by 68.3 % and 58.8 %, respectively, for non-impregnated and impregnated cores. The effect of impregnation of Testliner paper with modified starch on the strength of these boards for selected directions of orthotropy was also noticeable. For the (x) direction, the impregnation of the paper caused a reduction in value MOR_{px} of 19.0 %, while for direction (*y*) there was an increase in MOR_{py} of 5 %.

4 CONCLUSIONS
4. ZAKLJUČAK

The analysis of the obtained results of experimental and analytical calculations allows for the formulation of several important conclusions.

Slender hexagonal cells significantly differentiate their elastic properties in the main directions of orthotropy. In the (*x*) axis direction, the modulus of elasticity is approximately 3.7 times greater than in the (*y*) axis.

Impregnation of Testliner paper with modified starch reduces the values of the linear elasticity modulus of the cells by about 8.8 %.

The slender core cells differentiate the elastic properties of the cell plates in the main directions of orthotropy. In the (*x*) axis, the modulus of elasticity is about 355 % greater than in the direction of the (*y*) axis.

Impregnation of Testliner paper with modified starch reduces the values of linear elasticity modulus of honeycomb panels by at least 6.9 %.

Analytical solutions that do not include the structural form of the core cannot be used to calculate the modulus of elasticity of sandwich panels with hexagonal core cells.

Acknowledgements – Zahvala

The author would like to gratefully acknowledge the National Science Centre Poland for financing the present work as part of the research project No. 2016/21/B/ST8/01016.

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