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Characterization of Formaldehyde Emission and Combustion Properties of Peanut (*Arachis Hypogaea*) Husk-Based Green Composite Panels for Building Applications

Karakterizacija emisije formaldehida i svojstava gorenja ekoloških kompozitnih ploča za graditeljstvo proizvedenih na bazi ljusaka kikirikija (*Arachis hypogaea*)

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ABSTRACT • *The building sectors are increasingly in need of more wood-based panels. Forests and environments are being destroyed to produce these wood-based panels. The aim of this study is to protect forest assets by recycling peanut (Arachis hypogaea) husk and manufacturing particleboard for green building design. The manufactured composite panels were subjected to combustion and formaldehyde tests. According to the test results, peanut husk reduced the combustion time and increased the combustion temperature. Phenol-formaldehyde adhesive decreased illuminance values and the peanut husk ratio increased the illuminance values. It was understood that, when the peanut husk additive ratio increased, combustion times decreased. Slow-combustion of green building composite panels delays the danger of collapse in case of a fire in a building. The combustion performance of the composite panels can be improved by adding non-combustible materials that do not affect the adhesion performance of the composite panels. When the adhesive type is taken into consideration, it is seen that the FF additive ratio reduces the combustion time. According to the formaldehyde emission test results, 24 hours after the manufacturing process all composite panels met the requirements of the board formaldehyde class E1. These composite panels can be used in green buildings as a sustainable building material. The furniture industry can also use these agro-fiber composite panels as green materials.*

KEYWORDS: *particleboard; peanut husk; combustion properties; formaldehyde emission; green building materials*

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SAŽETAK • *Građevni sektor ima sve veću potrebu za pločama na bazi drva za čiju se proizvodnju uništavaju šume i okoliš. Cilj ovog istraživanja bio je zaštititi šumska dobra recikliranjem ljusaka kikirikija (Arachis hypogaea) i proizvodnjom iverica namijenjenih zelenoj gradnji. Na tako proizvedenim kompozitnim pločama provedena su ispitivanja gorenja i emisije formaldehida. Rezultati su pokazali da se dodavanjem ljusaka kikirikija smanjuje vrijeme gorenja i povećava temperatura izgaranja ploča. Fenol-formaldehidno ljepilo pridonosi smanjenju vrijednosti osvjetljenja, a uz veći udio dodanih ljusaka kikirikija povećava se razina osvjetljenja pri gorenju. Pretpostavljeno je da će se s povećanjem udjela ljusaka kikirikija smanjiti vrijeme gorenja. Sporo gorenje kompozitnih ploča namijenjenih zelenoj gradnji odgađa opasnost od urušavanja u slučaju požara u zgradi. Svojstva gorenja kompozitnih ploča mogu se poboljšati dodavanjem nezapaljivih materijala koji ne utječu na adheziju kompozitnih ploča. S obzirom na vrstu ljepila, ustanovljeno je da se s povećanjem udjela FF ljepila skraćuje vrijeme gorenja. Prema rezultatima ispitivanja emisije formaldehida 24 sata nakon procesa proizvodnje, sve su kompozitne ploče zadovoljile klasu emisije formaldehida E1. Zaključeno je da se ispitivane kompozitne ploče u zelenoj gradnji mogu upotrebljavati kao održivi građevni materijal. Kao ekološki prihvatljive, te se kompozitne ploče na bazi agrovlakana mogu primjenjivati i u industriji namještaja.*

KLJUČNE RIJEČI: *iverica; ljuska kikirikija; svojstva izgaranja; emisija formaldehida; zeleni građevni materijali*

1 INTRODUCTION
1. UVOD

There are important initiatives around the world to find sustainable, affordable building materials and technologies that meet the required comfort and safety standards. Along with the manufacturing of green building materials, improving the technological properties of recycled composite material based on agricultural residues is also an important approach to achieve this goal.

The use of building materials with minimum environmental impact contributes to the sustainable development of countries. Considering the environmental impact of selected materials in buildings can be an important method to improve the environmental performance of buildings. Today, there are many technologies to reduce environmental impacts, but these technologies need to be developed (Seyfang, 2010; Fernandez, 2006). Since 40 % of natural resources are used in the construction sector, buildings have a significant environmental impact. Besides, buildings are the cause of 30 % greenhouse gas emissions and an additional 18 % emission in the transport and use of building materials (Yudelson, 2008; Venkatarama *et al.,* 2003).

In recent years, sustainable design in the construction sector has been an important factor in preventing environmental problems. Architectural decisions such as orientation and mass and facade design have a significant impact on the strength and health of the building.

The physical, mechanical, and chemical properties of the chosen materials that are the basic components of a building are vital for a sustainable design. As a green design strategy, choosing eco-friendly sustainable building materials can be the fastest way to integrate into a sustainable design concept (Umar *et al.,* 2012). Therefore, the effective use of local and recycled building materials in the design can be a good strategy (Hulme and Radford, 2010; Fernandez, 2006). Peanut, which is one of the most produced agricultural residues in southern Turkey, is a local raw material that can be used for this purpose.

Non-wood lignocellulosic raw materials, as more sustainable materials, are in great demand due to the shortage of wood (Ulker and Burdurlu, 2016). The composite panel is produced by bonding wood fibers under heat and pressure with an adhesive. The building and furniture industries are in search of sustainable raw materials that can be used in composite panel production as an alternative to forest products. Recycling of lignocellulose agricultural wastes is a good alternative to composite panel production (Nemli and Aydin, 2007). In this way, forests can be protected and sustainable building and furniture material can be produced. Some agricultural wastes used in composite panel production are poppy husk (Keskin *et al.,* 2015), kiwi pruning wastes (Nemli *et al.,* 2007), pine cone (Buyuksari *et al.,* 2010), coffee husk and hulls (Bekalo and Reinhardt, 2010), vine pruning (Ntalos and Grigoriou, 2012), coconut fiber and castor oil (Fiorelli *et al.,* 2012) and cottonseed hulls (Gurjar, 1993). Composite panels to be used in the construction industry must meet some strength, combustion and surface quality standards. In general, it is tried to benefit from the wastes of annual plants in the production of composite panels. The Limit Oxygen Index (LOI) of the panels produced from poppy husk was determined as 48 % (Keskin *et al.,* 2015). It is seen that most agricultural wastes affect the strength values negatively.

Formaldehyde-based binders are commonly used to produce composite products found in furniture, cabinets, worktops, shelves and stair systems, floor coverings, and many other interior building materials. Formaldehyde (HCHO) adhesive is a poisonous material for the body especially for the nose and throat, but the eyes are the most sensitive to formaldehyde exposure. Moreover, it also causes more serious health problems such as asthma and cancer (Kim *et al.,* 2006). Poor indoor air quality affects human beings and causes health problems. Also, indoor air quality is one of the important factors that decrease the performance of the user (Reis *et al.,* 2006). Efforts are underway for interiors to reduce formaldehyde emissions by changing the chemical formulas of adhesives. Therefore, many wood manufacturers and researchers focus primarily on reducing or controlling the emission of formaldehyde from urea-formaldehyde adhesive-bonded composites. One of the reasons for formaldehyde emission is the presence of free formaldehyde in UF resins (Kim and Kim, 2005).

Wood has some advantages in case of fire. The most important advantage is the slow-burning of wood, which delays the danger of collapse, thus minimizing the loss of life. Improving the combustion properties of wood material and wood-based composites can further reduce the loss of life and property during fires (Terzi, 2008).

This study aims to produce a green building material that can reduce the effects of environmental problems and can be used for healthy building and furniture production. For this purpose, peanut husks were recycled under laboratory conditions to produce a sustainable, low formaldehyde emission and fire-retardant building material.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Peanut (*Arachis hypogaea*) husk
2.1. Ljuske kikirikija (*Arachis hypogaea*)

When the chemical structure of peanut husk was examined, it was found to be suitable for composite panel production, because it contains a high amount of cellulose and lignin. Peanut husk is reported to consist of 35-45 % cellulose, 27-33 % lignin, 60-67 % fiber, 6-7 % protein, 2-4 % ash, and 1-2 % fat (Kadiroglu, 2018). Peanut husks (*Arachis hypogaea*) used in the production of composite panels were obtained from Adana and Osmaniye provinces. Thinner peanut husk used in the outer layers were obtained by using a grinder. Coarse peanut husk used in the core layer were produced by using a 5 mm × 5 mm sieve. The thickness of the peanut husk is 0.1-0.5 mm, width is 2.1-7.8 mm and length is 1.1-7.9 mm. Peanut husks used in the core and outer layers are shown in Figure 1a and b.


a) b)

Figure 1 Peanut fibers: a) core layer fibers, b) outer layer fibers
Slika 1. Vlakna kikirikija: a) vlakna središnjeg sloja, b) vlakna vanjskog sloja

2.2 Wood particles
2.2. Drvne čestice

The fibers used in the production of composite panels were dried in an industrial dryer up to 1.4-3 % moisture and obtained from Yıldız Entegre, joint-stock company's composite panel factory in Bolu, Turkey. Wood fibers consist of 35 % Eastern Black Sea oak (*Quercus Pontica*), 45 % Black Pine (*Pinus nigra*), 10 % Aspen (*Populus tremula*), and 10 % workshop shav-


a) b)

Figure 2 Wood fibers: a) core layer fibers, b) outer layer fibers
Slika 2. Drvna vlakna: a) vlakna središnjeg sloja, b) vlakna vanjskog sloja

Table 1 Technical properties of adhesives
Tablica 1. Tehnička svojstva ljepila

Properties / *Svojstvo*	**UF**	**MF**	**FF**
Appearance / *Izgled*	White / *bijelo*	Transparent / *prozirno*	Red-brown / *crvenosmeđe*
Density (*ρ*) / *Gustoća (ρ)*	1.235-1.240 g/cm^3	1.225-1240 g/cm^3	1.200-1.210 g/cm^3
pH	7.5-8.7	8.5-9.5	10.5-13
Viscosity / *Viskoznost*	140-200 cP	100-200 cP	250-500 cP
Gelling time / *Vrijeme želiranja*	15 – 25 s.	70-110 s.	10-20 s.
Free formaldehyde / *Slobodni formaldehid*	Max.- 0.8 %	Max.- 0.8 %	Max.- 1 %
Mole ratio / *Molarni omjer*	1.45-1.55	1.80-1.85	1.50-1.55
Solid matter / *Suha tvar*	(55 ±1) %	(54 ±1) %	(55 ±1) %
Storage period / *Vrijeme skladištenja*	30 days/*dana*	20 days/*dana*	45 days/*dana*

Table 2 Experimental design
Tablica 2. Plan istraživanja

Panel type *Vrsta ploče*	**Peanut husk fiber, %** *Vlakna ljuske kikirikija, %*	**Wood fibers, %** *Drvna vlakna, %*	**Adhesive ratio, %** *Udio ljepila, %*	**Average density, g/cm³** *Srednja gustoća,* g/cm³
P1	100	0	100 UF	0.65
P2	100	0	95 UF + 5 MF	0.65
P3	100	0	95 UF + 5 FF	0.65
P4	75	25	100 UF	0.65
P5	75	25	95 UF + 5 MF	0.65
P6	75	25	95 UF + 5 FF	0.65
P7	50	50	100 UF	0.65
P8	50	50	95 UF + 5 MF	0.65
P9	50	50	95 UF + 5 FF	0.65
P10	25	75	100 UF	0.65
P11	25	75	95 UF + 5 MF	0.65
P12	25	75	95 UF + 5 FF	0.65

ings. There are no barks in the mixture formed. The thickness of the fibers varies between 0.2-0.6 mm, width 2.0-3.84 mm, and length 2.09-10.44 mm. The wood fibers used in the core and outer layers are shown in Figure 2a and b.

2.3 Adhesives
2.3. Ljepila

Urea-formaldehyde (UF), melamine-formaldehyde (MF) and phenol-formaldehyde adhesives are used in this study. Since these adhesives are widely used in the composite panel production industry, they were preferred for use in this research.

2.4 Methodology
2.4. Metodologija

Sustainable buildings and eco-design principles require low formaldehyde emissions and high fire resistance building materials. Composite panels used in the building and furniture sector should be produced in accordance with EN 312 (2010) product standard. The composite panels produced in this study were subjected to a combustion test according to ASTM E 160-50 (1975) standard and formaldehyde emission test according to EN 717-1 (2004) standard.

2.5 Preparation of testing samples
2.5. Priprema ispitnih uzoraka

The average density of manufactured composite panels was 0.65 g/cm³. The size of the composite panels was 18 mm × 500 mm × 500 mm. Since there are many studies on this subject, for the integrity of the results, we searched those studies and compared them. The experimental design of test samples can be seen in Table 2.

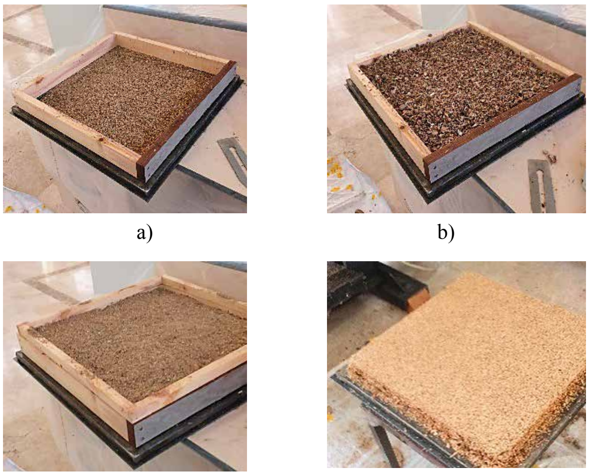
In order to determine a suitable adhesive rate, our previous studies and literature knowledge were taken into consideration. For this purpose, the ratio of the amount of adhesive used in the outer layers and the core layer to the total dry fiber mass was determined as 10 %. Press area was 50 cm ×50 cm and draft board panel thickness was assumed to be 18 mm with a total volume value of 4500 cm³.

The hardener was used in the prepared adhesive solution of 1 % ammonium sulfate $(NH_4)_2SO_4$. The production parameters of composite panels are displayed in Table 3.

Gluing was carried out using an adhesive gun in a circular moving mixer. A 60 cm × 60 cm guide forming frame was used in the preparation of the composite panel outline. The laying process was carried out in the forming frame, and three layers were produced by laying the surface, middle and other surface layers, respectively. 65 % of the thickness of the slab was formed by the core layer and 35 % by outer layers. The laying process was carried out homogeneously without disturbing the composite panel layers. The spreading process is shown in Figure 3a, b, and c.

Table 3 Production parameters of composite panels
Tablica 3. Proizvodni parametri kompozitnih ploča

Parameter / *Parametar*	**Value** / *Vrijednost*
Press temperature, ºC *temperatura prešanja,* °C	165
Pressing time, min *vrijeme prešanja,* mm	7
Peak pressure, N/mm² *najveći tlak,* N/mm²	0.25
Thickness, mm *debljina,* mm	18
Dimensions, mm *dimenzije*, mm	500 × 500
$(NH_4)_2SO_4$, %	1
Outer layer, % *vanjski sloj,* %	35
Core layer, % *središnji sloj*, %	65
Number of panels for each type *broj ploča iste vrste*	5



a) b) c) d)

Figure 3 Spreading process: a) outer layer, b) core layer, c) outer layer, d) after cold press
Slika 3. Postupak natresanja: a) vanjskog sloja, b) središnjeg sloja, c) vanjskog sloja, d) nakon hladnog prešanja

After completing the laying, the guide frame was removed and a cold-press was applied to the composite panel outline. After the cold-press, the composite panel draft was put into a hot press process. The composite panel outline after the cold-press is shown in Figure 3d.

In the hot pressing process, an electrically heated press, having an area of 60 cm × 60 cm, was used. After the hot press process, the composite panels were kept in the air conditioning cabinet for 24 hours.

2.6 Combustion test
2.6. Ispitivanje gorenja

The composite panels were manufactured in accordance with ASTM E 160-50 standard for the determination of the combustion properties. Before the combustion test, 72 test samples were prepared for each board type with the dimensions of 76 mm × 76 mm × 13 mm. Each sample group was weighed and stacked on the stand according to the test standard. The flame height was kept constant at (25±1.3) cm when the maker was empty and the gas pressure at the manometer was 0.5 kg/cm^2. In the funnel part, where the thermocouple is mounted, combustion was carried out at a temperature of (215±8) °C. The flame source was centered under the stack and flame-induced combustion (CWF) was continued for 3 minutes. Following the extinction of the flame source, the self-combustion (CWOF) and the core combustion (ECP) stages were performed. Measurements in the combustion stages were made at 15 s. 30 s. and 30 s. respectively, and temperature changes were read from the thermometer.

2.7 Formaldehyde emission test
2.7. Ispitivanje emisije formaldehida

The formaldehyde (HCHO) emission (FE) of the manufactured composite panels was determined in accordance with the European Norm EN 717-1. Formaldehyde emission levels of the manufactured composite panels were determined at Gazi University, Faculty of Technology Woodworking Industrial Engineering Department Wood Laboratory. Tests were carried out with a Multi-RAE lite PGM 6208 formaldehyde detector that works with photoionization technology. The test samples were placed in the test chamber, which allowed the test samples to remain under constant temperature and humidity, and formaldehyde emission (FE) values were measured.

FE was evaluated in accordance with EN 717-1. According to this method, test samples were placed in a constant humidity chamber with controlled temperature,

Table 4 Formaldehyde emission standards for composite panels in Europe and the USA (Groah *et al.*, 1991)
Tablica 4. Norme za emisiju formaldehida kompozitnih ploča u Europi i SAD-u (Groah *et al.*, 1991.)

Country *Država*	**Standard** *Norma*	**Test method** *Ispitna metoda*	**Board class** *Klasa ploče*	**Limit value** *Granična vrijednost*
Europe	EN 13986, 2004	EN 717-1	E1	≤ 0.1ppm (≤ 0.124 mg/m^3)
		EN 120		≤ 8 mg/100
		EN 717-2		≤ 3.5 mg/m^2 h
		EN 717-1	E2	> 0.1 ppm (> 0.124 mg/m^3)
		EN 120		> 8 ≤ 30 mg/100
		EN 717-2		> 3.5 ≤ 8.0 mg/m^3 h
Australia & New Zealand	AS/NZS 1859-1, 2004	AS/NZS	E0	≤ 0.5 mg/L
		4266.16, 2004	E1	≤ 1.5 mg/L
		(Desiccator)	E2	≤ 4.5 mg/L
USA	ANSI A 208.1, 2009	ASTM E 1333	PB	≤ 0.18 ppm Phase 1 (2009)
		(large chamber)		≤ 0.09 ppm Phase 2 (2011)
Japan	JIS A 5908, 2003	JIS A 1460		≤ 1.5 mg/L
		(Desiccator)		≤ 0.5 mg/L
				≤ 0.3 mg/L

[a] At 23 °C and 1013 hPa, the following relationship exists for formaldehyde measured by EN 717-1: 1 ppm = 1.24 mg/m^3 or 1 mg/m^3 = 0.81 ppm
[a] *Pri 23 °C i 1013 hPa za formaldehid izmjeren prema EN 717-1 odnos je ovakav: 1 ppm = 1,24 mg/m^3 ili 1 mg/m^3 = 0,81 ppm.*

the air was continuously replaced and the test was completed when the emission reached a stable value. The international limiting values for the formaldehyde parameters of composite panels are presented in Table 4.

2.8 Data analyses
2.8. Analiza podataka

The aim of this study was to determine the effect of the peanut husk ratio, adhesive type, and its contents on the formaldehyde emission and combustion properties of the composite panel. One-way analysis of variance (ANOVA) was used to check the significant difference between factors and levels. When the ANOVA showed a prominent difference among factors and levels, a comparison of the means was defined by the Duncan test to see whether the differences between the groups were consequential or not.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Combustion temperatures
3.1. Temperature gorenja

In this study, combustion temperatures were measured in three steps. These steps can be expressed as combustion with flame (CWF), combustion without flame source (CWOF), and ember combustion phase (ECP). The highest temperatures of 187.00 °C, 406.67 °C and 145.00 °C during CWF, CWOF, and ECP, respectively, were observed in P1 type composite panels. The lowest temperatures of 313.67 °C, 147.67 °C and 99.67 °C during CWOF, CWF and ECP, respectively, were observed in P12 type composite panels. Combustion temperatures according to composite panel types are shown in Table 5.

According to the combustion steps, the highest temperature was measured during the CWOF process. In the combustion phase, the lowest temperature was achieved in the ECP. The highest combustion temperature was determined as 406.67 °C in the composite panels produced solely from peanut husk. The combustion temperatures of the composite panels produced with 100 % peanut husk additive (P1) were found highest. According to this; combustion temperatures (°C) were found as 187.00 °C in CWF stage, 406.67 °C in CWOF stage and 145 °C in ECP stage. It was observed that, when the peanut husk ratio decreased, the combustion temperatures also decreased. We have not found a relationship between adhesives and combustion temperatures. Considering the Duncan test results, in combustion stages, peanut husk ratio increases CWF, CWOF and ECP.

Peanut husk contains cellulose, lignin, and fat (Kadiroglu, 2018). The fat contained in peanut husk may have increased the combustion temperature.

By increasing the ratio of phenol-formaldehyde adhesive and adding boron minerals, the combustion properties of the composite panels produced with peanut husk can be improved. During CWF, CWOF, and ECP stages, combustion temperatures were 480 °C, 603 °C and 333 °C, respectively, in the combustion test of the Caucasian spruce (*Picea orientalis* L.) wood (Groah *et al.,* 1991).

As a result of research on the effect of glass wool and Rock wool on the combustion properties of particleboards, adhesive type did not affect ignition time and

Table 5 Combustion temperatures during combustion stages
Tablica 5. Temperature gorenja tijekom faza gorenja

Panel type *Vrsta ploče*	**Combustion with flame (CWF), °C** *Gorenje s plamenom (CWF) °C*	**HG**^{a}	**Std**$_{cwf}$	**Combustion without flame source (CWOF), °C** *Izgaranje bez izvora plamena (CWOF), °C*	**HG**^{a}	**Std**$_{cwfo}$	**Ember combustion (ECP), °C** *Sagorijevanje žara (ECP), °C*	**HG**^{a}	**Std**$_{ecp}$
P1	187.00	a	12.74	406.67	a	29.93	145.00	a	13.28
P2	167.00	de	10.86	372.00	cd	26.91	120.00	f	11.79
P3	152.00	ij	11.51	343.67	h	27.31	108.33	jk	12.67
P4	154.33	hi	11.29	321.67	i	29.39	116.67	fg	11.94
P5	171.67	bc	11.04	391.00	ab	28.13	136.33	bc	12.27
P6	160.33	g	10.92	350.33	fg	26.98	114.00	hi	12.12
P7	164.67	ef	10.84	362.00	de	26.74	125.67	de	11.73
P8	149.33	jk	11.80	321.00	ij	29.47	112.00	ij	12.29
P9	167.33	d	10.87	372.00	cd	26.91	126.00	cd	11.73
P10	174.33	b	11.21	380.33	bc	27.30	138.67	ab	12.50
P11	156.33	h	11.14	355.00	ef	26.83	114.33	gh	12.10
P12	147.67	lm	12.01	313.67	jk	30.47	99.67	l	13.87
LSD = ± 6.74 °C				LSD = ± 24.32 °C			LSD = ± 8.51 °C		

[a] Homogeneous group ($p<0.05$) / *homogene skupine ($p<0,05$)*

mass loss. While flaming combustion temperature of PB with UF was 19 % higher, flaming combustion duration and smoldering combustion duration was 32 % and 29 % lower than that of PB with MF, respectively.

3.2 Illuminance values
3.2. Vrijednosti osvjetljenja

During the first combustion stage, combustion with flame (CWF), the highest illuminance values were observed in composite panels P8 produced using 50 % peanut husk fibers and 50 % wood fibers and 95 % UF and 5 % MF. During CWF, the lowest illuminance values were observed in composite panels P8 produced using 50 % peanut husk fibers and 50 % wood fibers, and 95 % UF and 5 % FF. According to these results, FF adhesive decreased illuminance values.

During the second combustion stage (CWOF), the highest illuminance value was measured in composite panels P3 produced with 100 % peanut husk and 95 % UF, 5 % FF. The lowest illuminance values were observed in composite panels P10 produced using 25 % peanut husk and 100 % urea-formaldehyde adhesive.

During the third combustion stage, the ember combustion phase (ECP), the highest illuminance values were observed in composite panels P8 produced using 50 % peanut husk fibers and 50 % wood fibers, and 95 % UF and 5 % MF. During ECP, the lowest illuminance values were found in composite panels P5 produced using 75 % peanut husk fibers and 25 % wood fibers, and 95 % UF and 5 % MF. According to these results, FF adhesive decreased illuminance values. Table 6 shows the illuminance values according to composite panel types.

According to combustion type, the highest illuminance values of 976.07 lux were observed in the ECP and the lowest of 952.55 lux in the CWF stage. According to the peanut additive ratio, the highest illuminance values of 968.92 lux were observed in 50 % peanut added composite panels. The lowest illuminance values of 952.21 lux were observed in composite panels with 75 % peanut husk additive. When the adhesive type is considered, the illuminance values of 5 % FF + 95 % UF glued composite panels are measured as 974.03 lux. The illuminance value of the composite panels produced with 100 % UF adhesive was 954.03 lux.

Considering the data obtained from the experiments and Duncan test results, it was observed that there were statistical differences between the produced panels. However, there was no correlation between the peanut husk ratio and adhesive type with illuminance values during combustion stages. The results of production on an industrial scale may produce more pronounced results than the panels produced in the laboratory.

A high illuminance value means less smoke. Less smoke reduces the risk of smoke poisoning. It is seen that there is no significant difference between the test samples in terms of smoke density. Therefore, it can be said that composite panels produced with wood fibers and composite panels produced with peanut husk have similar properties.

3.3 Combustion times and mass loss
3.3. Vrijeme gorenja i gubitak mase

During combustion stages, the shortest combustion time was observed in P3 type composite panels as 1440.00 sec. The longest combustion time was ob-

Table 6 Illuminance values during combustion stages
Tablica 6. Vrijednosti osvjetljenja tijekom faza gorenja

Panel type *Vrsta ploče*	**Combustion with flame (CWF), lux** *Gorenje s plamenom (CWF),* lux	**HG**^{a}	**Std**$_{cwf}$	**Combustion without flame source (CWOF), lux** *Izgaranje bez izvora plamena (CWOF),* lux	**HG**^{a}	**Std**$_{cwfo}$	**Ember combustion (ECP), lux** *Sagorijevanje žara (ECP),* lux	**HG**^{a}	**Std**$_{ecp}$
P1	987.67	bc	35.07	944.00	gh	27.64	973.00	gh	32.82
P2	952.06	i	34.37	938.77	hi	27.80	908.07	mn	37.84
P3	983.94	cd	34.87	995.78	a	30.04	984.42	f	32.89
P4	960.59	gh	34.28	983.78	ab	28.87	1006.71	bc	33.89
P5	915.69	l	36.51	934.89	ij	27.97	931.39	lm	35.07
P6	909.24	lm	37.17	946.28	fg	27.59	981.30	fg	32.84
P7	996.91	ab	35.70	979.48	bc	28.53	1004.51	cd	33.74
P8	1005.24	a	36.41	975.76	cd	28.28	1012.14	a	34.30
P9	896.97	mn	38.61	910.97	k	29.86	938.28	l	34.44
P10	983.07	de	34.82	903.54	kl	30.71	965.07	hi	32.95
P11	965.58	fg	34.31	949.41	f	27.55	999.98	de	33.47
P12	975.11	ef	34.50	967.98	de	27.87	1008.00	ab	33.98
LSD = ± 19.46 lux				LSD = ±17.64 lux			LSD = ±12.49 lux		

^{a}Homogeneous group ($p<0.05$) / *homogene skupine (p<0,05)*

Table 7 Combustion times and mass loss during combustion stages
Tablica 7. Vrijeme gorenja i gubitak mase tijekom faza gorenja

Panel type *Vrsta ploče*	**Combustion, sec** *Gorenje, s*	**HG**[a]	**Std$_c$**	**Mass loss, %** *Gubitak mase, %*	**HG**[a]	**Std$_{wl}$**
P1	1547.78	h	244.99	46.50	a	7.33
P2	1506.67	hg	248.89	34.87	ea	6.50
P3	1440.00	i	256.16	30.82	g	6.57
P4	1715.56	fg	234.23	29.42	gb	6.64
P5	1783.33	e	232.39	42.23	b	6.86
P6	1733.33	f	233.60	30.20	ga	6.60
P7	2021.11	c	237.90	35.02	e	6.51
P8	1973.33	cd	235.32	25.70	h	6.93
P9	1984.44	cd	235.86	40.51	c	6.73
P10	2080.00	ab	242.03	39.02	d	6.63
P11	2093.33	A	243.11	33.55	f	6.51
P12	2098.89	A	243.58	23.97	i	7.11
LSD = ± 828.17 sec			LSD = ± 1.28 %			

[a] Homogeneous group ($p<0.05$) / *homogene skupine (p<0,05)*

served in P12 type composite panels as 2098.89. The highest mass loss (46.50 %) was observed in P1 type composite panels. The lowest mass loss (23.97 %) was observed in P12 type composite panels. Combustion times and mass loss are shown in Table 7.

Combustion times, according to the peanut additive ratio and adhesive type, were detected longest in P12 as 2098.89 seconds, while the shortest time decreased by 31.33 %, seen in P3 boards as 1440.00 seconds. It has been determined that the boards with more peanut husk additives burned faster and that their burning time was shorter than that of the boards with less additives. This could be explained by the fact that the peanut husk burned faster than wood fibers and the charring time was longer in wood fibers. As a result of the experiments, it was understood that when the peanut husk additive ratio increased, combustion time was reduced.

The total mass loss was measured as 46.50 % in P1 boards. As the peanut husk additive ratio decreased, total mass loss also decreased and it was 23.97 % in P12 boards. Regarding the total mass losses, it has been determined that the peanut husk showed incineration faster at lower temperatures than wood fibers. As a result, it was determined that the total mass loss at the end of the combustion process increased as the peanut husk additive ratio increased. When the adhesive type is taken into consideration, it is seen that the FF additive ratio reduced the combustion time because of the characteristics of the adhesive.

According to the result of research on the effect of glass wool and rock wool on the combustion properties of particleboards, adhesive type did not affect ignition time and mass loss. While flaming combustion temperature of PB with UF was 19 % higher, flaming combustion duration and smoldering combustion duration was 32 % and 29 % lower than that of PB with MF, respectively (Ulker and Burdurlu, 2015).

3.4 Formaldehyde emissions

3.4. Emisija formaldehida

Engineered wood composites, including plywood, particleboard, and fiberboard, used as furniture components, mostly contain formaldehyde resins as adhesive. Adhesives, flame-retardant chemicals, and paints are used in engineered wood products (EWPs) to increase some of the properties of wood. (Ulker and Ulker, 2019). Some issues should be considered when using recycled wood wastes for further reutilization, such as the release of formaldehyde from particleboard used as an interior building product due to incompletely reacted urea-formaldehyde (UF), melamine-formaldehyde (MF), and phenol-formaldehyde (PF) resins in particleboard. As a result, indoor air quality can worsen, posing a major health concern, particularly in modern homes and workplaces, which are often more airtight than older buildings.

Formaldehyde emissions were measured twice for each board - one hour and 24 hours after production. Formaldehyde emission test results after composite panel production are shown in Table 8.

The results of formaldehyde emission one hour after manufacturing were approximately 70 % higher than the results after 24 hours. The emission values returned to an acceptable level after 24 hours. The result is displayed in Figure 4.

We found a negative relationship between wood fiber additive ratios and formaldehyde emissions. This can be explained by the lower bonding performance among the peanut husks. When the peanut husk additive ratio increased, formaldehyde emission values also increased.

The lowest formaldehyde emission values were observed in the mixture of 95 % UF + 5 % MF adhesives in P11 type composite panel, and the highest formaldehyde emission values were obtained in compos-

Table 8 Formaldehyde emissions
Tablica 8. Emisije formaldehida

Panel type *Vrsta ploče*	**One hour after composite panel manufacturing, ppm** *Jedan sat nakon izrade kompozitne ploče,* ppm	Std_{1h}	**24 hours after composite panel manufacturing, ppm** *24 sata nakon izrade kompozitne ploče,* ppm	Std_{24h}
P1	0.28	0.03	0.08	0.01
P2	0.24	0.03	0.06	0.01
P3	0.26	0.03	0.06	0.01
P4	0.26	0.03	0.06	0.01
P5	0.22	0.03	0.04	0.01
P6	0.26	0.03	0.06	0.01
P7	0.25	0.03	0.05	0.01
P8	0.23	0.03	0.05	0.01
P9	0.23	0.03	0.05	0.01
P10	0.21	0.03	0.06	0.01
P11	0.17	0.03	0.03	0.01
P12	0.20	0.03	0.06	0.01

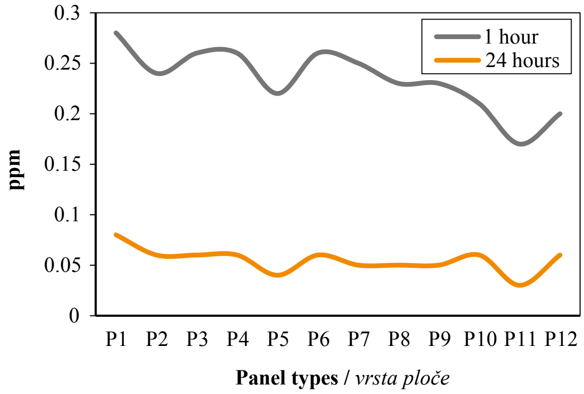


Figure 4 Formaldehyde emission results
Slika 4. Vrijednosti emisije formaldehida

ite panels made solely with the peanut husk P1 type composite panels.

Composite panels often have problems with satisfying board formaldehyde emission requirements of the El class, which stipulates a maximum emission of 0.1 ppm formaldehyde emission. The composite panels were tested 24 hours after the manufacturing process. According to the test results, all manufactured composite panels met the requirements of E1 board formaldehyde class. These composite panels may be suitable for indoor air quality conditions for green buildings. The coating of the composite panel and the low mole ratio of formaldehyde in adhesive may be further reduced to the FE in the manufactured panel.

4 CONCLUSIONS
4. ZAKLJUČAK

The manufactured composite panels were subjected to combustion and formaldehyde tests. The highest combustion temperatures of 187.00 °C, 406.67 °C and 145.00 °C were observed during CWF, CWOF and ECP, respectively, in P1 type composite panels. The lowest temperatures during of 313.67 °C, 147.67 °C and 99.67 °C during CWOF, CWF and ECP, respectively, were observed in P12 type composite panels.

The combustion temperatures of the composite panels produced with 100 % peanut husk additive (P1) were found highest. According to this, combustion temperatures of 187.00 °C were found in CWF stage, 406.67 °C in CWOF stage and 145 °C in ECP stage. It was observed that, when the peanut husk ratio decreased, the combustion temperatures also decreased. We have not found a relationship between adhesives and combustion temperatures.

During the first combustion stage, combustion with flame (CWF), the highest illuminance values were observed in composite panels P8 produced using 50 % peanut husk fibers and 50 % wood fibers, and 95 % UF and 5 % MF. During CWF, the lowest illuminance values were observed in composite panels P8 produced using 50 % peanut husk fibers and 50 % wood fibers, and 95 % UF and 5 % FF. According to these results, FF adhesive decreased illuminance values.

In terms of peanut additive ratio and adhesive type, the longest combustion time of 2098.89 seconds was detected in P12, while the shortest time of 1440.00 seconds, with a decrease of 31.33 %, was observed in P3 boards. It has been determined that the panels with more peanut husk additives burn faster and that the burning time is shorter than that of the boards with less additives. This could be explained by the fact that the peanut husk burned faster than wood fibers and the charring time was longer in wood fibers. As a result of the experiments, it was understood that when the peanut husk additive ratio increased, combustion time was reduced.

The total mass loss was measured as 46.50 % in P1 boards. As the peanut husk additive ratio decreased, total mass loss also decreased and it was 23.97 % in P12 boards. Regarding the total mass losses, it has been determined that the peanut husk showed incineration faster at lower temperatures than wood fibers. As a result, it was determined that the total mass loss at the end of the combustion process increased as the peanut husk additive ratio increased. When the adhesive type is taken into consideration, it is seen that the FF additive ratio reduced the combustion time because of the characteristics of the adhesive.

According to the test results, all manufactured composite panels met the requirements of E1 board formaldehyde class. These composite panels may be suitable for indoor air quality conditions for green buildings. The coating of the composite panel and the low mole ratio of formaldehyde in adhesive may be further reduced to the FE in the manufactured panel. We found a negative relationship between wood fiber additive ratios and formaldehyde emissions. This can be explained by the lower bonding performance among the peanut husks. When the peanut husk additive ratio increased, formaldehyde emission values also increased.

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