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The Effect of Nano TiO_2 and Nano Boron Nitride on Mechanical, Morphological and Thermal Properties of WF/PP Composites

Utjecaj nanočestica titanova dioksida i nanočestica boron nitrida na mehanička, morfološka i toplinska svojstva WF/PP kompozita

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ABSTRACT • *This study evaluated the effect of nano boron nitride (BN) and nano titanium dioxide (TiO_2) on some physical, mechanical and thermal properties of WF/PP composites. Polyproplene as a polymer matrix and wood flour obtained from particleboards were used as reinforcing fillers to prepare the composites by using a single screw extruder. It was observed that density in all composites did not change significantly with the increasing of wood flour. It was found that BMOR and BMOE of the composites increased with the increasing of the wood flour content and nanoparticle types, while the TMOR and TMOE decreased. According to the results of thermal properties (TGA), thermal degradation of all composites was found to be lower compared with pure PP.*

Keywords: *wood polymer composites, natural fillers, nanoparticle type, characterization analysis*

SAŽETAK • *U radu je predočeno istraživanje utjecaja nanočestica borova nitrida (BN) i nanočestica titanova dioksida (TiO_2) na neka fizikalna, mehanička i toplinska svojstva drvno-plastičnih kompozita (WF/PP kompozita). Za proizvodnju kompozita upotrijebljeni su polipropilen kao polimerna matrica i drvno brašno dobiveno od ploča iverica kao punilo, uz pomoć jednovijčanog ekstrudera. Uočeno je da se gustoća kompozita ne mijenja značajno s povećanjem količine drvnog brašna. Utvrđeno je da se BMOR i BMOE kompozita povećava s povećanjem sadržaja drvnog brašna i nanočestica TiO_2 i BN-a, dok se TMOR i TMOE smanjuju. Prema rezultatima istraživanja toplinskih svojstava (TGA), zaključeno je da je toplinska degradacija svih istraživanih kompozita manja u usporedbi s čistim polipropilenom.*

Ključne riječi: *drvno-plastični kompoziti, prirodna punila, vrsta nanočestica, analiza svojstava*

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1 INTRODUCTION
1. UVOD

Wood-plastic composites (WPCs) are principally concerned with thermoplastic polymers reinforced by wood and wood derivatives such as fibers or flour (Soccalingame *et al*., 2016). Wood flour (WF) actually represented a waste material, which had to be eliminated from sawmills in the past. Many waste utilization strategies have been introduced over the last century, such as bedding, composting, combustion, gas generation, use as feedstock for chemical industry, etc. Among them, the use of WF as raw material for making new solids is the most positive due to its convenience in application and low energy costs (Ashori, 2008; Okamoto, 2003).

In general, wood flour is used as plastic filler, which tends to increase the stiffness of the composite but does not improve its strength. Natural fibers can be used to reinforce plastics rather than filler rate, which increases strength as well as stiffness. Natural fibers can be used to reinforce filled plastics, by increasing both strength and stiffness. Wood and other lignocellulosic fibers typically have higher particle sizes than those of wood flour (Osswald and Menges, 1995). WPCs combine the best properties of the pure components and can show superior performance in many application areas. Compared with potential traditional competitors, WPCs offer better thermal and acoustic isolation than aluminum, better durability and lower maintenance than wood, and often lower price than pure plastics (Garcia *et al*., 2009).

Lignocellulosic materials have made significant contributions to the thermoplastic industry, which has led to the emergence of wood–plastic composites in the construction industry. Products such as decking, fencing, siding, window framing, and roof tiles are being introduced into the market. The use of WPCs is also increasing in construction, transportation, industrial and consumer industries. Growing interest in renewable resources-based products is due to social and environmental concerns. Commercial thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), and styrene maleic anhydride (SMA) are commonly used in the manufacture of plastic/wood fiber composites (Sobczak *et al*., 2013; Bledzki and Gassan, 1999; Rowell *et al*., 1997; Zor *et al*., 2016). The use of technical and standard plastics has approached the application of natural fibers thanks to their low prices and steadily rising performance (Wittig, 1994). The composites reinforced with wood have shown a great growth due to many advantages. Their processing is easy, economic, and ecological. They have relatively high strength and stiffness, low cost, low density, low CO_2 emission, and they are biodegradable and renewable (Deka and Maji, 2011). However, these polymers have low thermal conductivities. Therefore, some researchers have worked to improve the thermal conductivity and electrical insulation of polymers by adding different fillers and fire retardants.

Boron nitride (BN) has been widely used in the thermal management industry for years. BN is a good lubricant and abrasive, and it has a high thermal conductivity, high electrical resistance, and high temperature resistance. The familiar structures of BN are the hexagonal (hBN) and cubic (cBN) crystal structures. The structure of hBN is more stable than that of cBN (Meneghetti *et al*., 2008). BN is a low atomic numbered nonmetallic compound; its melting temperature (~3000 °C) is too high to be used for thermal insulation. BN/polymer composites can decrease thermal expansion and increase thermal conductivity, while enhancing the electrical insulation properties (Zhou *et al*., 2007). Also, the addition of a small amount of BN in polymers might enhance their extrusion by increasing their flowablity (Jung *et al*., 2010). Nano TiO_2 particle is one of the promising inorganic nano fillers used in polymer matrix composites to enhance the mechanical properties (Nayak *et al*., 2016; Bardak *et al*., 2016). Among the investigated inorganic nano fillers, TiO_2 nanopowder is being increasingly investigated because it is non-toxic, chemically inert, low cost, corrosion resistant and has a high refractive index, UV filtration capacity and high hardness (Mirabedini *et al*., 2008).

The goal of this research was to investigate the usability of wood flour obtained from particleboards in wood plastic composites. Furthermore, the effects of nano TiO_2 and nano BN on the physical, mechanical and thermal properties of WF/PP composites have determined.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials
2.1. Materijali

Wood flours (WF) were supplied by Kastamonu Entegre Ağaç Sanayi A.Ş. Wood flours consist of 50 % *Gymnospermae* (*Pinus nigra* Arn. and *Pinus sylvestris* L.) wood and 50 % *Angiospermae* wood (*Fagus orientalis* L. and *Populus alba* L.). Oven-dry densities of WFs used in the study were 0.54 g·cm^{-3}, 0.48 g·cm^{-3}, 0.63 g·cm^{-3} and 0.40 g·cm^{-3}, respectively. All WF samples were of the same size made using 0.5 mm sieve. Polypropylene (EH241) was supplied by PETKIM Inc, in Turkey. The properties of the PP – EH241 are listed in Table 1.

Table 1 Properties of polypropylene (EH241)
Tablica 1. Svojstva polipropilena (EH241)

Properties / *Svojstva*	**Values** *Vrijednost*
Melt flow index, g/10 min (at 230 °C / 2.16 kg) *indeks fluidnosti,* g/10 min *(pri 230* °C */ 2,16* kg*)*	5 to 20
Density / *gustoća*, g·cm^{-3}	0.92
Water absorption / *upijanje vode*, %	0.1
Processing temperature / *temperatura obrade*, °C	160-170
Tensile modulus / *modul elastičnosti*, MPa	35
Flexural modulus / *modul savitljivosti*, GPa	1.5
Izod Impact, notched / *otpornost na udarce*, kJ·m^{-2}	2

Titanium dioxide (TiO_2) was supplied by mkNANO (Canada). Titanium dioxide nano powder (MKN-TiO_2-015P: Hydrophilic TiO_2) was amorphous and 99.5 % pure. The size of TiO_2 was 50 nm. The specific surface area of titanium dioxide is 150 $m^2 \cdot g^{-1}$.

Hexagonal boron nitride (hBN) was supplied by BORTEK – BOR Technologies, Inc. Boron nitride has the formula BN, so it consists of boron and nitrogen elements. The hexagonal formation is stable and softest among the BN polymorphs. Boron nitrides cannot be naturally obtained, so they are chemically synthesized by reacting boron trioxide or boric acid with ammonia or urea (Rudolph 2000, Robert and Chaitanya 1990). The h-BN has a specific gravity of 2.27 $g \cdot cm^{-3}$ and a melting range of 2700-3000 °C. It consists of thin plates that have an average diameter of about 200 nm and a thickness of 80 nm (Ayrilmis *et al*., 2014).

2.2 Methods
2.2. Metode

WF was oven dried at 103±2 °C to obtain moisture content less than 1 %. PP was used as matrix polymer, while WF was used as fillers. Loading ratios of WF were 10 and 20 % wt. Nano materials (nano TiO_2 and nano boron nitride) loading level varied from 0.5 to 1 % by compounding weight (1000 gr). A general survey of PP/WF compound after mechanical mixing is shown in Figure 1. The production formulations are given in Table 2.

The materials used in the compounding were first mixed to achieve better dispersion by mechanical mixer for 15 minute. The obtained samples were extruded at 50 rpm by a single screw extruder. During the extrusion, the zone temperatures ranged from 170 to 180 °C, the melting pressure of the extruder varied between 5 and 10 bars depending on material blends, the screw speed was 50 rpm, and the material output was 1 $kg \cdot h^{-1}$. When exiting the extrusion, the obtained compounds, which were melted, were cooled and solidified directly in a water-cooling system, while being pulled with end drive conveyors. Then, the solidified materials were pelletized through a pelletizer. The pellets obtained were injection molded to obtain the test samples. All samples were conditioned at 20 °C and 65 % relative humidity prior to tests. First, the weights of samples (*m*) were measured by 0.001 g precision scales. Sample volumes (*V*) were calculated using dimensions and densities (*D*) of samples determined according to $D=m/V$ equation.

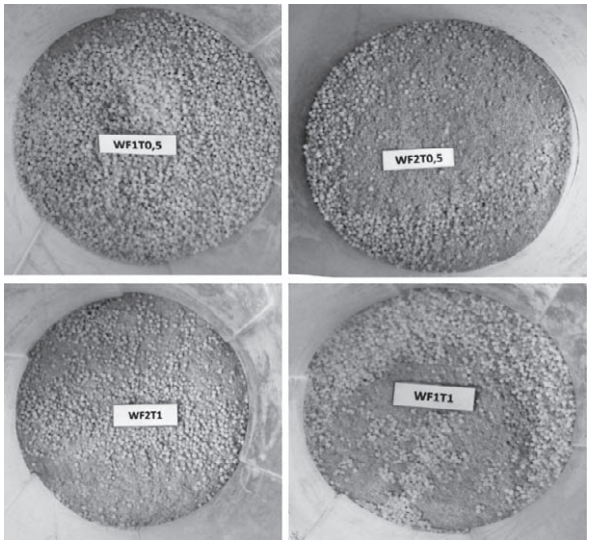

Figure 1 PP/WF compounds
Slika 1. Spojevi PP/WF

Table 2 Materials and ratios used in the study
Tablica 2. Materijali upotrijebljeni u eksperimentu i njihovi omjeri

Sample code *Oznaka uzorka*	**Polypropylene** *Polipropilen* %	**Filling material** *Punilo* %	**Nano material** *Nanomaterijal* %	**Type of nano material** *Vrsta nanomaterijala*
Neat PP	100	-	-	-
PP+W1	90	10	-	-
PP+W2	80	20	-	-
PP+W1B0.5	89.5	10	0.5	BN
PP+W1B1	89.	10	1	BN
PP+W1T0.5	89.5	10	0.5	TiO_2
PP+W1T1	89.	10	1	TiO_2
PP+W2B0.5	79.5	20	0.5	BN
PP+W2B1	79	20	1	BN
PP+W2T0.5	79.5	20	0.5	TiO_2
PP+W2T1	79	20	1	TiO_2

The samples were air dried at 70 °C until a constant weight was reached prior to the immersion in a water bath. The specimens were periodically taken out of the water, wiped with tissue paper to remove surface water, reweighed and measured again and immediately put back into the water. The water absorption of the composites was determined according to ASTM D 1037-93.

Bending strength (*BMOR*), flexure modulus (*BMOE*), tensile strength (*TMOR*) and tensile modulus (*TMOE*) were determined according to ASTM D 790-03 Test Method 1 and ASTM D 638-03 Type I, respectively. These tests were conducted using a Zwick tester with a 10-kN load cell capacity. Test speed was used at a rate of 0.2 $inch \cdot min^{-1}$ for all tests. The izod impact strength (IIS) tests were conducted according to ASTM D 256-06. The notches were provided with a NotchVIS machine (Ceast trademark) and tests were performed with a Resil 50 B impact tester. The morphological properties of the samples were observed with a scanning electron microscope (SEM) (TESCAN MAIA3) with an accelerating voltage of 15 kV under nitrogen. The fracture parts of all samples were sputter-coated with gold using a Denton sputter coater for enhanced conductivity. The thermal stability of all the composites was investigated using a TGA and DSC (Perkin Elmer, TA Instruments, USA). When using a TGA, the samples were heated from 25 ºC to 600 ºC with a heating rate of 10 ºC/min and a nitrogen flow of 100 $mL \cdot min^{-1}$. The samples weighing about 10 mg were used for the tests. Degradation temperatures at 10 %

weight loss ($T_{10\%}$) and 50 % weight loss ($T_{50\%}$), maximum degradation temperature in the derivative thermogravimetric peaks (DTG_{max}), and mass loss of the samples in the TGA curves were measured and compared with the results obtained.

One-way analysis of variance (ANOVA) was performed to identify significant differences at the 99 % confidence level. The Duncan test was used to determine the difference between groups. The important differences between formulations were shown with letters, such as A, B, C, and D.

3. RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical and mechanical properties
3.1. Fizikalna i mehanička svojstva

The highest density was determined to be 0.94 g·cm^{-3} in pure PP samples. This was followed, in order, by PP+W1B1, PP+W1 and PP+W1T1 samples. The lowest density was obtained in the W2T1 sample. Low density of wood flour is the factor with the highest impact on decreasing densities. Densities of WFs used in the study varied between 0.40 g·cm^{-3} (*Pinus nigra* Arn.) and 0.63 g·cm^{-3} (*Fagus orientalis* L.). There is a significant difference in variations (F_{ratio} = 4.706; P_{value} = 0.000 < 0.05) according to one–way analysis of the variance (ANOVA). Homogeneity within variations was determined by using Duncan test. Figure 2 and Table 3 show densities and homogeneity groups of WPC, respectively.

Figure 2 and Figure 3 show that the addition of wood flour increased *BMOR* and *BMOE* values. The highest value of *BMOR* was found to be 51.60 MPa in the PP+W1B1 samples. PP+W2B2 samples showed the highest *BMOE* with 2207 MPa strength. Control samples (Pure PP) showed the lowest *BMOR* value with 41.80 MPa and *BMOE* with 1256 MPa, respectively. Supporting WPC with wood flour resulted in the increase of 23.4 % in the bending strength (PP+W1B1), 75 % in the modulus of elasticity (PP+W2B1). Bouafif *et al*., (2009) state that lignocellulosic materials increased the bending and tension strength as well as elasticity modules in bending and tension tests. *BMOR* and *BMOE* values are shown in Figure 3 and Figure 4, respectively.

Table 3 The homogeneity groups of WPC
Tablica 3. Homogene skupine drvno-plastičnih kompozita

Sample code / *Oznaka uzorka*	**Groups** / *Skupine*	
PP+WF1BN0.5	0.8665	A
PP+WF1T0.5	0.8694	AB
PP+WF2	0.8764	ABC
PP+WF1T1	0.8915	ABCD
PP+WF2BN1	0.8928	BCD
PP+WF1	0.8930	BCD
PP+WF2T0.5	0.8989	CD
PP+WF2BN0.5	0.9029	D
PP+WF1BN1	0.9053	D
PP+WF2T1	0.9087	D
Pure PP	0.9360	E

The multi-way ANOVA analysis was conducted to find the effects of nanoparticle type, nanoparticle rates and filler rate on bending strength of WPC and the obtained data are given in Table 4.

The effect of nanoparticle rate (0.5 % and 1 %), nanoparticle type (TiO_2 and BN) and filler rate (10 % and 20 %) on the *BMOR* was found to be significant according to the result of Duncan test as seen in Table 5. The effect of interaction of nanoparticle type and filler rate on the bending strength was statistically significant. Duncan test was applied to determine the differences between groups. The effects of nanoparticle rate, nanoparticle type and filler material rate on the bending strength are given in Table 5. Increasing in nanoparticle rate increased proportionally both *BMOR* and *BMOE* values (Table 5.1). BN increased the *BMOR* strength, while TiO_2 contributed to the development of *BMOE* strength. It can be said that BN is more effective in bending resistance when compared to TiO_2 (Table 5.2). Adding wood flour to pure PP increased the *BMOR* and *BMOE*, but the filler rate was not important in *BMOR* test according to Table 5.3.

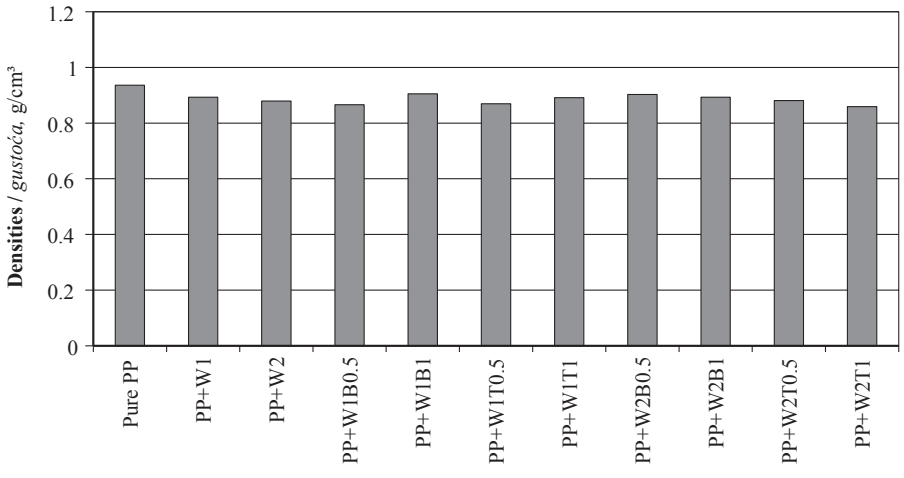

Figure 2 Densities of WPC
Slika 2. Gustoća istraživanih drvno-plastičnih kompozita

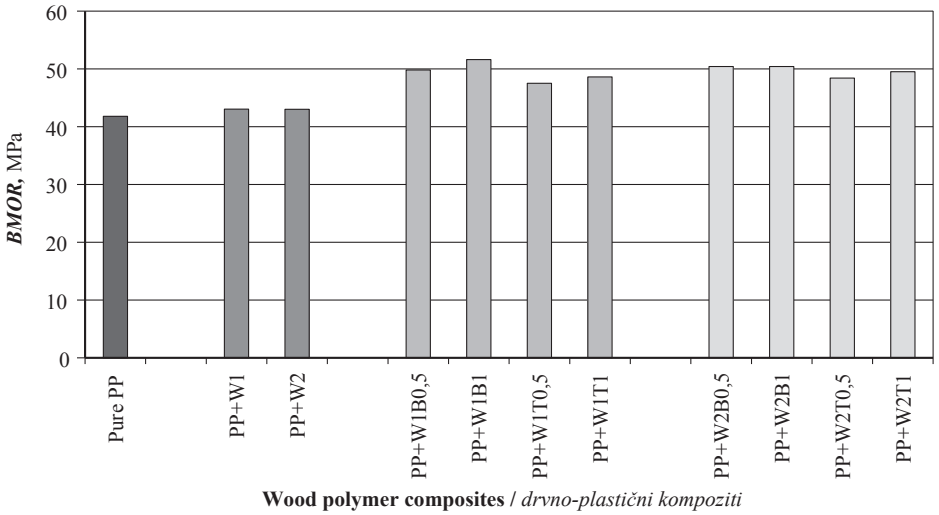

Figure 3 *BMOR* values of WPC
Slika 3. Čvrstoća na savijanje istraživanih drvno-plastičnih kompozita

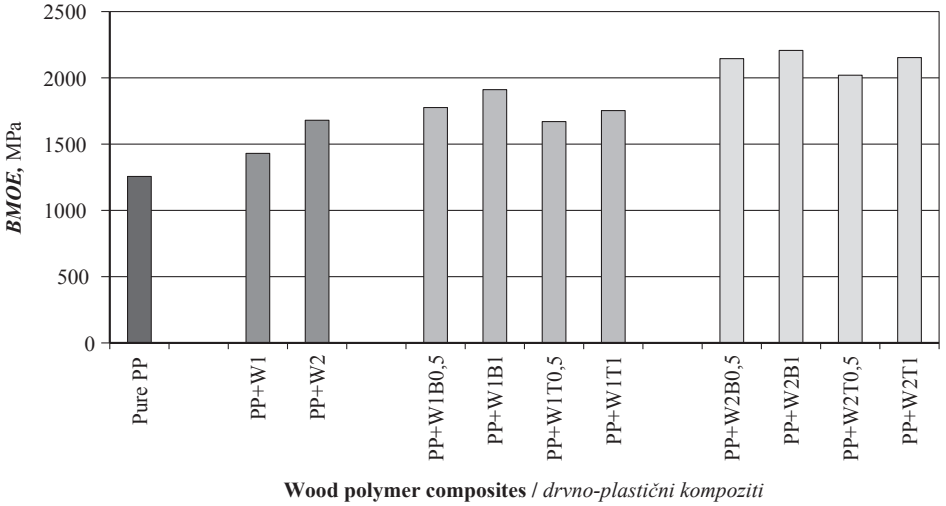

Figure 4 *BMOE* values of WPC
Slika 4. Modul elastičnosti pri savijanju istraživanih drvno-plastičnih kompozita

Table 4 Multi-way ANOVA analysis done for the effects of nanoparticle type, nanoparticle rate and filler rate on bending strength of WPC
Tablica 4. Višefaktorska ANOVA analiza utjecaja vrste nanočestica, količine nanočestica i količine punila na čvrstoću savijanja drvno-plastičnih kompozita

Source / *Izvor varijabilnosti*	**Type III Sum of Squares** *Zbroj kvadrata*	***df***	**Mean Square** *Srednja vrijednost kvadrata*	***F***	**Sig.**
Corrected model / *korigirani model*	575.056[a]	10	57.506	85.748	.000
Intercept / *presjek*	114171.222	1	114171.222	1.702E5	.000
Filler rate (A) / *udjel punila (A)*	5.040	2	2.520	3.757	.031
Nanoparticle type (B) / *vrsta nanočestica (B)*	40.381	1	40.381	60.213	.000
Nanoparticle rate (C) *količina nanočestica (C)*	8.621	1	8.621	12.855	.001
(A) * (B)	4.363	1	4.363	6.505	.014
(A) * (C)	2.093	1	2.093	3.121	.084
(B)* (C)	0.281	1	0.281	0.418	.521
(A) * (B) *(C)	2.678	1	2.678	3.993	.052
Error / *pogreška*	29.508	44	0.671		
Total / *ukupno*	125208.989	55			
Corrected Total / *ispravljeno ukupno*	604.564	54			

Table 5 Effect of nanoparticle rate (A), nanoparticle type (B) and filler rate (C) on *BMOR* according to Duncan test
Tablica 5. Utjecaj količine nanočestica (A), vrste nanočestica (B) i količine punila (C) na čvrstoću na savijanje istraživanih kompozitnih materijala prema Duncanovu testu

Nanoparticle rate / *Količina nanočestica*	**Groups** / *Skupine*		
	A	B	C
Control	42.61		
0.5 %		49.00	
1 %			49.92

A)

Nanoparticle type / *Vrsta nanočestica*	**Groups** / *Skupine*		
	A	B	C
Control	42.61		
TiO_2		48.46	
BN			50.46

B)

Filler rate *Količina punila*	**Groups** *Skupine*	
	A	B
Control	41.82	
10 %		48.07
20 %		48.27

C)

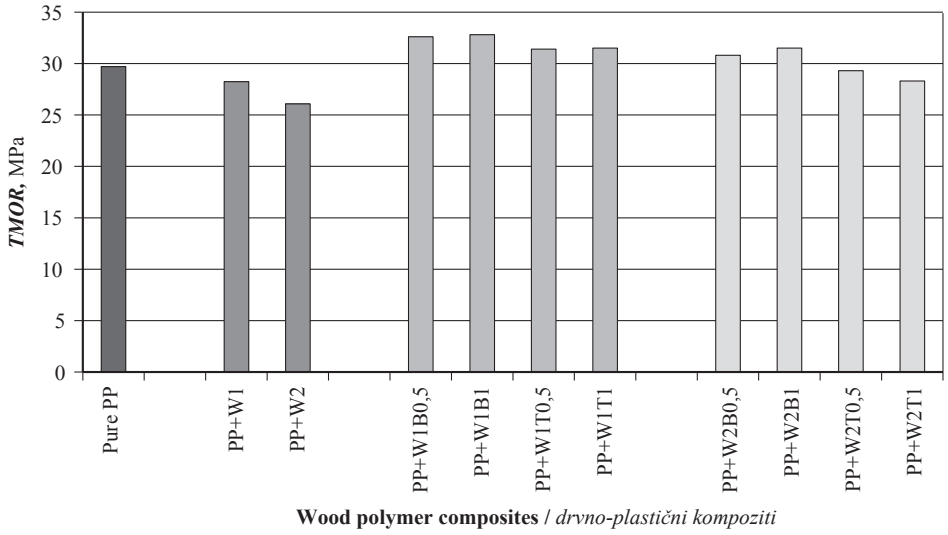

Figure 5 *TMOR* values of WPC
Slika 5. Vlačna čvrstoća istraživanih drvno-plastičnih kompozita

Figure 5 and Figure 6 show *TMOR* and *TMOE* values of the samples, respectively. *TMOR* of pure PP was determined as 29.7 MPa. Decreasing was observed in *TMOR* values of PP+W1 and PP+W2 samples. These decreases were calculated to be 4.94 % and 12.2 %, respectively. All samples containing nano boron nitride showed increased *TMOR* values when compared to control samples. *TMOE* of pure PP increased in all of the samples. The highest increase in *TMOE* of PP+W2B1 and PP+W2B0.5 was determined to be 83 % and 75.8 %, respectively.

According to the multi-way ANOVA analysis, it was found that the filler rate (A), nanoparticle type (B) and nanoparticle rate (C) were statistically significant at 0.05. Table 6 shows the results of multi-way ANOVA analysis.

It was found that the interaction between filler rate (1) and nanoparticle rate (3) was not significant. In-

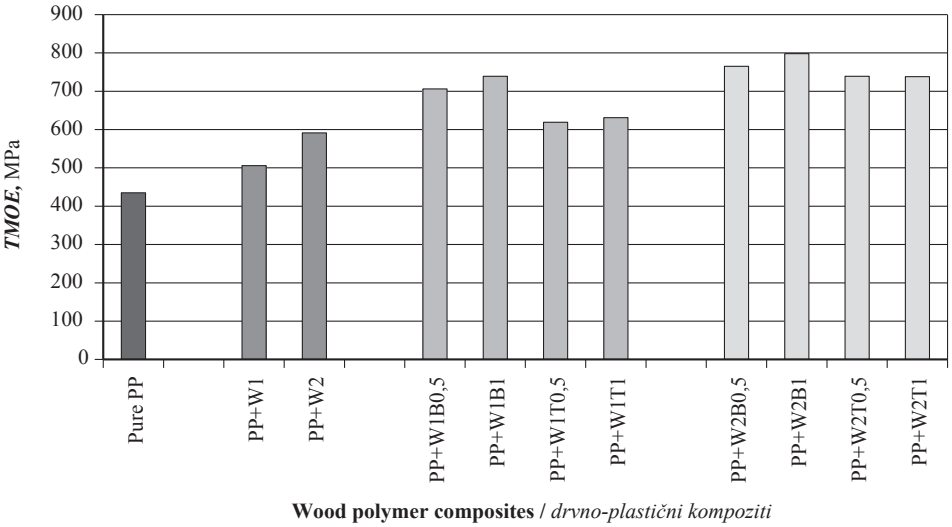

Figure 6 *TMOE* values of WPC
Slika 6. Vlačni modul elastičnosti istraživanih drvno-plastičnih kompozita

Table 6 Multi-way ANOVA analysis determining the effects of nanoparticle type, nanoparticle rate and filler rate on tensile strength of WPC
Tablica 6. Višefaktorska ANOVA analiza utjecaja vrste nanočestica, količine nanočestica i količine punila na vlačnu čvrstoću drvno-plastičnih kompozita

Source / *Izvor varijabilnosti*	**Type III Sum of Squares** *Zbroj kvadrata*	***df***	**Mean Square** *Srednja vrijednost kvadrata*	***F***	**Sig.**
Corrected model / *korigirani model*	216.347[a]	10	21.635	94.949	.000
Intercept / *presjek*	46710.972	1	46710.972	2.050E5	.000
Filler rate (A) / *udjel punila (A)*	76.101	2	38.051	166.994	.000
Nanoparticle type (B) / *vrsta nanočestica (B)*	32.256	1	32.256	141.564	.000
Nanoparticle rate (C) / *količina nanočestica (C)*	.018	1	0.018	.081	.777
(A) * (B)	2.948	1	2.948	12.940	.001
(A) * (C)	.331	1	0.331	1.454	.234
(B)* (C)	2.116	1	2.116	9.287	.004
(A) * (B) *(C)	1.706	1	1.706	7.486	.009
Error / *Pogreška*	10.026	44	0.228		
Total / *Ukupno*	50316.722	55			
Corrected Total / *ispravljeno ukupno*	226.373	54			

creasing the rate of wood flour decreased the tensile strength of WPC when compared to control samples. However, adding nanoparticles to WF/PP compound led to a significant increase. It can be said that BN provided a better fit with wood flour than TiO_2. The effects of nanoparticle rate (1), nanoparticle type (2) and filler rate (3) on the *TMOR* are according to the results of Duncan test. The related test results are shown in Table 7.

As seen in Figure 7, the highest izod impact strength (IIS) was obtained in PP+W1and PP+W2 samples, 2.17 kJ·m^{-2} and 2.07 kJ·m^{-2}, respectively. The lowest IIS was determined in W1samples, which contained 0.5 % of nano boron nitride. Generally, it can be said that nanoparticles decreased the izod impact strength of WF/PP composites.

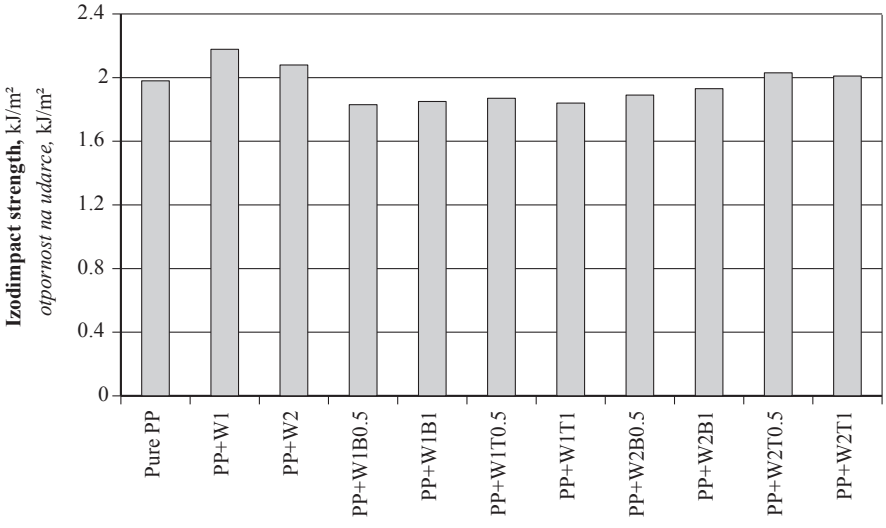

Figure 7 Izod impact strength (IIS) values of WPC
Slika 7. Otpornost na udarce (IIS) istraživanih drvno-plastičnih kompozita

Table 7 Effect of nanoparticle rate (A), nanoparticle type (B) and filler rate (C) on *TMOR* according to Duncan test
Tablica 7. Utjecaj količine nanočestica (A), vrste nanočestica (B) i količine punila (C) na vlačnu čvrstoću istraživanih kompozitnih materijala prema Duncanovu testu

Nanoparticle rate *Količina nanočestica*	**Groups** *Skupine* A	B
Control	27.99	
0.5 %		30.97
1 %		31.01

A)

Nanoparticle type *Vrsta nanočestica*	**Groups** *Skupine* A	B	C
Control	27.99		
TiO_2		30.09	
BN			31.89

B)

Filler rate *Količina punila*	**Groups** *Skupine* A	B
20 %	29.15	
Control	29.68	
10 %		31.30

C)

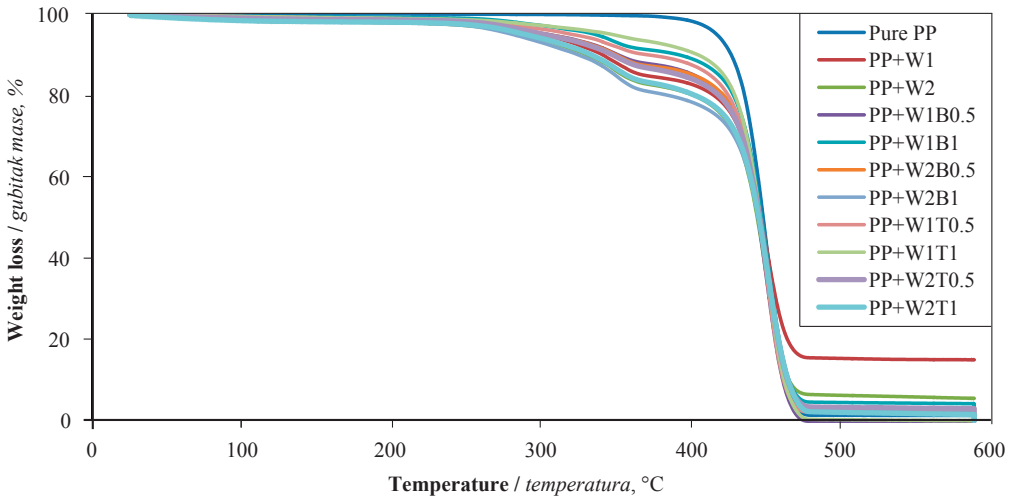

Figure 8 TGA curves of WPC
Slika 8. TGA krivulje istraživanih drvno-plastičnih kompozita

3.2 Thermal Characterization
3.2. Toplinska svojstva

Thermal stability of the samples was investigated using TGA/DTG analysis. As sees in Fig 8, it can be said that no significant difference occured in TGA analysis with the addition of nanoparticle types and filler. The fastest mass losses were observed in samples containing PP+W2T1 and PP+W2NB1. On the other hand, the PP+W1T1 curve was the nearest to the curve of pure PP. Onset temperature of the composites was also determined to decrease with adding the nanoparticle types and filler. Similarly, as the filler loading increased, the thermal stability of the composites slightly decreased, whereas the final ash content monotonically increased (Kiziltas *et al*., 2011a, b).

DTG curves in Figure 9 showed maximum degradation at 453 °C for W2NB1%, and the peaks of the composites were found to be between 350 °C and 470 °C. As seen in Table 8, DTA curves indicated the two peaks of melting peak (T_m) and decomposition peak (T_d). It is well known that PP, which is extremely hygroscopic in nature, is consumed at 426 °C without formation of any char residue (Baeza and Freer, 2001).

As seen in Table 8, the maximum value of T_m was found in the wood composites with 1%NB (167.5 °C), whereas the minimum value of T_m was determined in the wood composites with 1%NB. T_d values, the maximum and minimum values, were found to be 1%NB and 0.5%T, respectively. The summary of the thermogravimetric analysis is presented in Table 8.

4 CONCLUSIONS
4. ZAKLJUČAK

Adding wood flour has no significant effect on the density of WPC composites. The *BMOR* and *BMOE* of the composites were increased both with the addition of wood flour and nanoparticle rate. The *TMOR*, *TMOE* and izod impact strength of the composites were negatively affected by the increase of the rate of wood flour. It was found that thermal stability of the composites (TGA) decreased with both nanoparticle

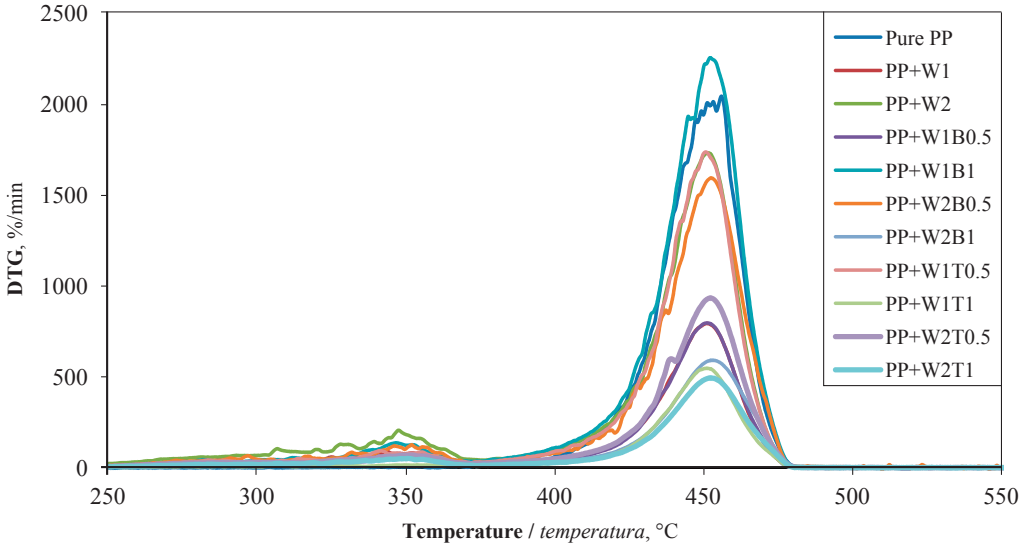

Figure 9 DTG curves of WPC
Slika 9. DTG krivulje istraživanih drvno-plastičnih kompozita

Table 8 Summary of thermogravimetric analysis
Tablica 8. Sažetak termogravimetrijske analize

Samples *Uzorci*	$T_{10\%}$ °C	$T_{50\%}$ °C	$T_{90\%}$ °C	**Residue** %	DTG_{max} °C	T_m °C	T_d °C
PP	427.0	448.3	463.3	98.7	456.0	166.4	450.3
PP+W1	341.18	447.15	465.3	84.9	451.0	158	448.2
PP+W2	330.22	444.39	465.4	94.7	451.5	159.6	451.2
PP+W1B0.5	351.4	444.9	461.4	99.8	451.1	163.4	450.9
PP+W1B1	392.2	447.2	465.4	95.9	452.1	167.5	451.5
PP+W2NB0.5	350.2	446.3	464.6	98.0	452.6	165.6	452.3
PP+W2NB1	324.9	445.2	465.5	98.2	453.0	161.8	456.4
PP+W1T0.5	371.6	445.4	461.8	98.3	450.7	165.9	450.1
PP+W1T1	404.9	446.3	463.0	99.8	451.0	162.3	450.5
PP+W2T0.5	347.6	445.9	464.6	97.1	452.2	164.4	451.4
PP+W2T1	333.6	445.4	464.9	98.5	452.1	163.1	455.8

types. It was concluded that wood flour obtained from particleboards in WPCs has a significant effect on the material characterization (mechanical properties, thermal properties, etc.). Based on the findings obtained from the present study, the use of W1T1 can further increase mechanical performance of all composites.

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